US010759276B2

(12) United States Patent

Onaka et al.

(10) **Patent No.: US 10,759,276 B2**

(45) **Date of Patent: Sep. 1, 2020**

(54) **MAGNETIC SENSOR AND DETECTION DEVICE USING SAME**

(71) Applicant: **Panasonic Intellectual Property Management Co., Ltd.**, Osaka (JP)

(72) Inventors: **Kazuhiro Onaka**, Hyogo (JP); **Shigehiro Yoshiuchi**, Kyoto (JP); **Noritaka Ichinomiya**, Nara (JP); **Kiyotaka Yamada**, Kyoto (JP)

(73) Assignee: **PANASONIC INTELLECTUAL PROPERTY MANAGEMENT CO., LTD.**, Osaka (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 47 days.

(21) Appl. No.: **16/093,741**

(22) PCT Filed: **Jun. 27, 2017**

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§ 371 (c)(1),
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PCT Pub. Date: **Jan. 18, 2018**

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(30) **Foreign Application Priority Data**

Jul. 12, 2016	(JP)	2016-137291
Jul. 12, 2016	(JP)	2016-137292

(Continued)

(51) **Int. Cl.**

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G01B 7/30	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***B60K 20/02*** (2013.01); ***G01B 7/30*** (2013.01); ***G01D 5/245*** (2013.01); ***G01R 33/02*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC B60K 20/02; H01L 27/22; H01L 43/08; H01L 43/065; H01L 43/06; G01R 33/02;

(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,039,410 A *	3/2000	Robertson	B60T 7/20 188/3 R
6,064,197 A	5/2000	Lochmann et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

JP	4-026227	1/1992
JP	6-310776	11/1994

(Continued)

OTHER PUBLICATIONS

International Search Report of PCT application No. PCT/JP2017/023466 dated Sep. 26, 2017.

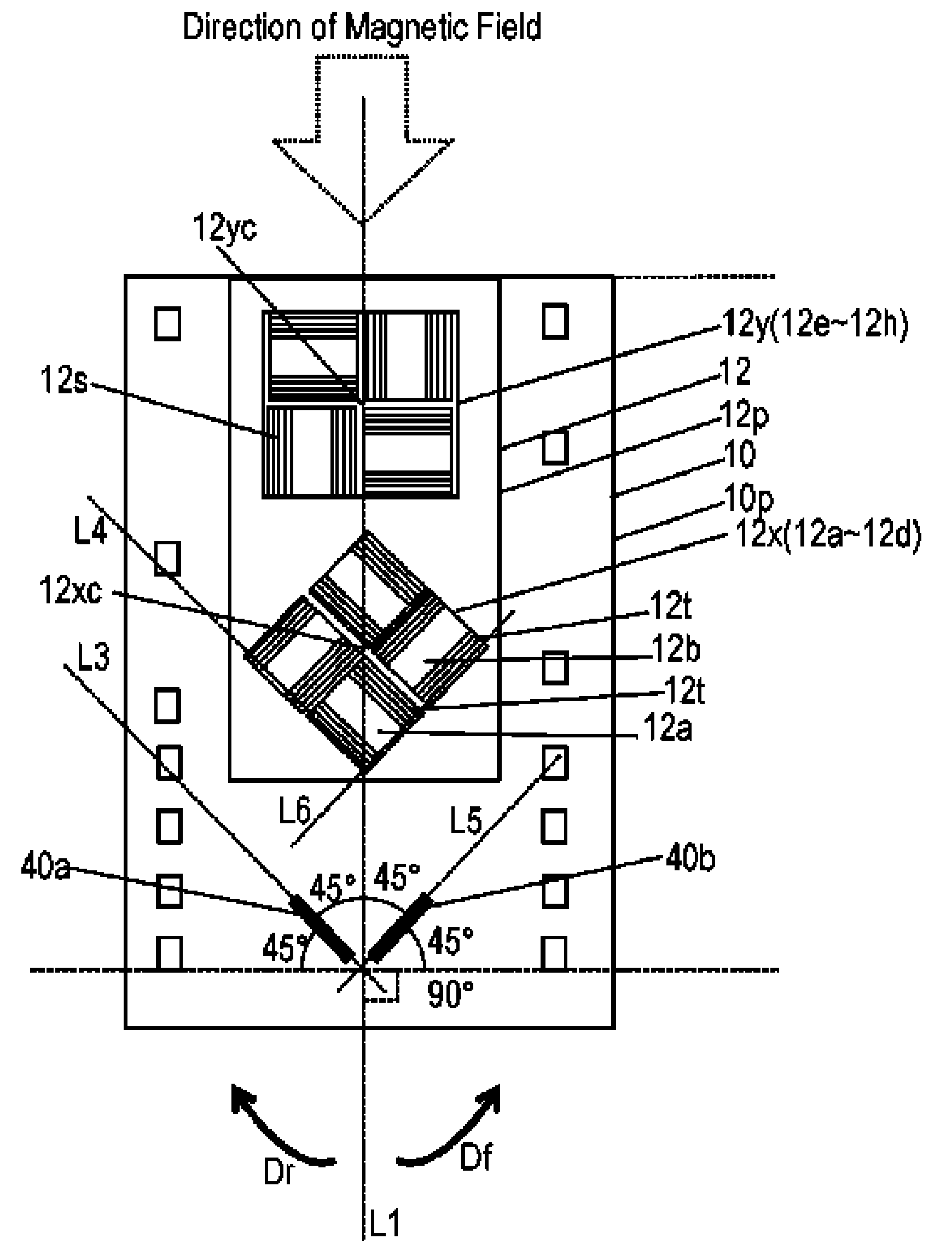
Primary Examiner — Christopher P McAndrew

(74) *Attorney, Agent, or Firm* — McDermott Will & Emery LLP

(57) **ABSTRACT**

A magnetic sensor includes a magneto-resistive element, a Hall element, and a detection circuit that receives a signal from the magneto-resistive element and a signal from the Hall element input thereto. The detection circuit includes an output terminal and an interrupt generation unit. The output terminal outputs, to the outside as an output signal, a signal obtained by performing to the signal input from the magneto-resistive element, at least one processing selected from amplification, analog-to-digital conversion, offset correc-

(Continued)



tion, and temperature-characteristics correction. The interrupt generation unit outputs an interrupt signal when the signal input from the Hall element is larger than a predetermined threshold. The magnetic sensor is high accurate and highly reliable.

7 Claims, 33 Drawing Sheets

(30) **Foreign Application Priority Data**

Aug. 2, 2016 (JP) 2016-151648
Jan. 17, 2017 (JP) 2017-005561

(51) **Int. Cl.**

G01R 33/09	(2006.01)
G01R 33/02	(2006.01)
G01D 5/14	(2006.01)
H01L 43/08	(2006.01)
H01L 27/22	(2006.01)
G01D 5/245	(2006.01)
H01L 43/06	(2006.01)

(52) **U.S. Cl.**
CPC ***G01R 33/09*** (2013.01); ***H01L 27/22*** (2013.01); ***H01L 43/08*** (2013.01); *G01D 5/145* (2013.01); *H01L 43/06* (2013.01); *H01L 43/065* (2013.01)

(58) **Field of Classification Search**
CPC G01R 33/09; G01D 5/245; G01D 5/145; G01B 7/30
USPC 324/207.13
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,252,395	B1	6/2001	Aoyama et al.	
7,208,940	B2 *	4/2007	Withanawasam	G01D 5/14 324/207.21
7,906,961	B2	3/2011	Abwa et al.	
8,841,776	B2	9/2014	Nishimura et al.	
9,151,809	B2	10/2015	Astegher et al.	
9,588,134	B2 *	3/2017	Ausserlechner	G01R 33/07
2002/0111763	A1	8/2002	Koga	
2003/0090265	A1 *	5/2003	Wan	G01D 5/145 324/207.25
2004/0131887	A1	7/2004	Ao et al.	
2006/0158141	A1 *	7/2006	Frank	B60T 7/042 327/511
2009/0058407	A1	3/2009	Kanekawa et al.	
2009/0212771	A1	8/2009	Cummings et al.	
2010/0097733	A1 *	4/2010	E.	H02H 1/0015 361/42
2011/0018533	A1	1/2011	Cesaretti et al.	
2012/0313636	A1	12/2012	Cummings et al.	
2013/0335066	A1	12/2013	Cesaretti et al.	
2015/0175191	A1	6/2015	Harada et al.	
2015/0198678	A1	7/2015	Pilla	
2015/0300840	A1 *	10/2015	Haeberle	G01R 33/09 324/207.21
2016/0146635	A1 *	5/2016	Sato	G01D 5/145 324/207.22
2016/0377453	A1 *	12/2016	Kimura	G03B 3/10 324/207.11
2017/0098520	A1 *	4/2017	Mittelstadt	G01D 5/145

FOREIGN PATENT DOCUMENTS

JP	11-287668		10/1999
JP	2002-213944		7/2002
JP	3474096	B	12/2003
JP	2004-172430		6/2004
JP	2005-521597		7/2005
JP	2006-234495		9/2006
JP	2007-155668		6/2007
JP	2007-203976		8/2007
JP	2007-333489		12/2007
JP	4138952	B	8/2008
JP	4863953	B	1/2012
JP	5083281	B	11/2012
JP	2014-209124		11/2014
JP	5620989	B	11/2014
JP	5638900	B	12/2014
JP	2015-082633		4/2015
JP	5708986	B	4/2015
JP	2015-108527		6/2015
JP	2015-116964		6/2015
JP	5961777	B	8/2016
WO	2003/085481		10/2003
WO	2014/148087		9/2014

* cited by examiner

FIG. 1A

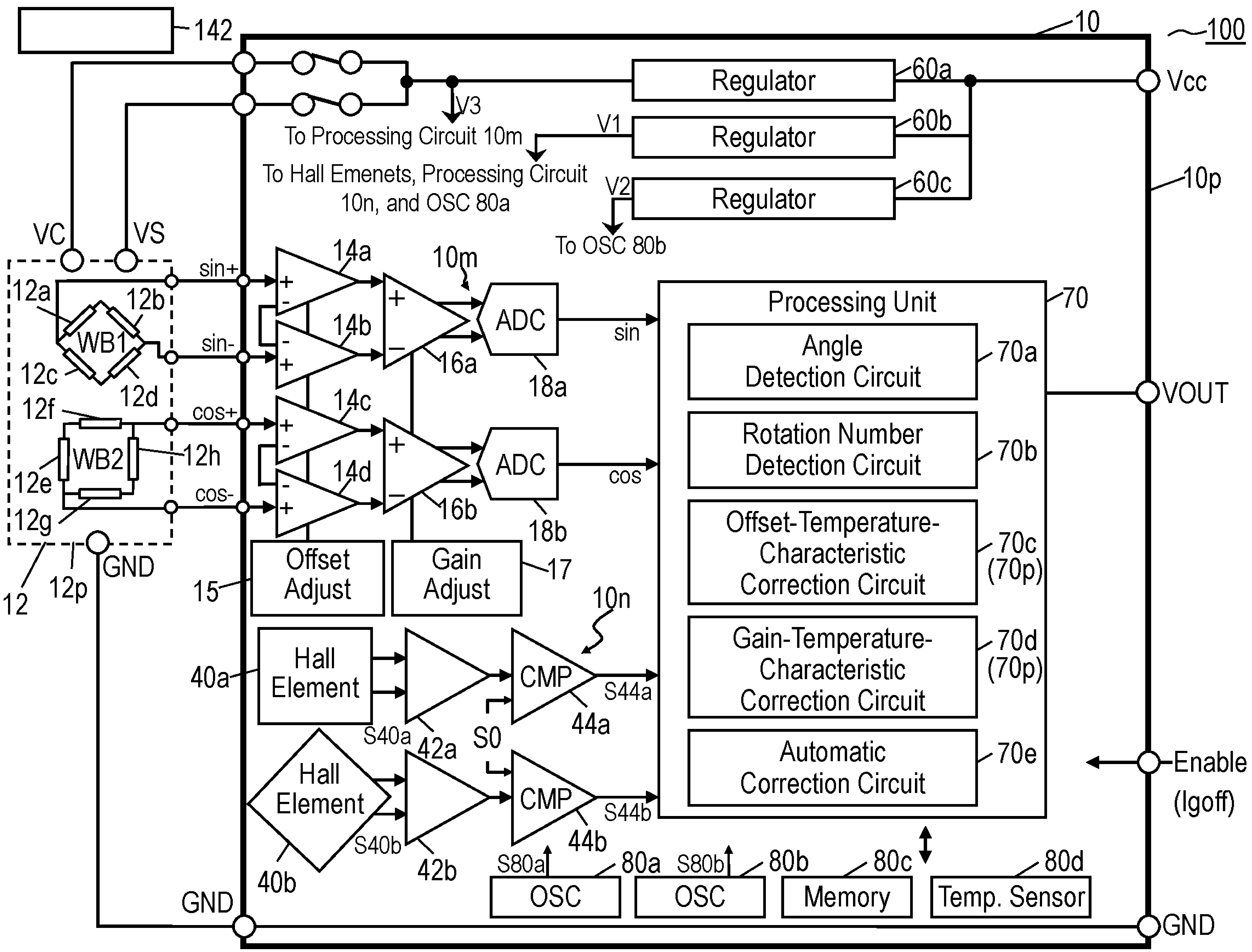

142
10
100
Vcc
Regulator
60a
V3
V1
Regulator
60b
To Processing Circuit 10m
To Hall Emenets, Processing Circuit
10n, and OSC 80a
V2
Regulator
60c
10p
To OSC 80b
VC
VS
12a
12b
WB1
12c
12d
12f
WB2
12h
12e
12g
12
12p
GND
sin+
sin-
cos+
cos-
14a
14b
14c
14d
10m
16a
16b
ADC
18a
ADC
18b
sin
cos
Processing Unit
70
Angle
Detection Circuit
70a
Rotation Number
Detection Circuit
70b
Offset-Temperature-
Characteristic
Correction Circuit
70c
(70p)
Gain-Temperature-
Characteristic
Correction Circuit
70d
(70p)
Automatic
Correction Circuit
70e
VOUT
Enable
(Igoff)
Offset
Adjust
15
Gain
Adjust
17
10n
Hall
Element
40a
S40a
42a
S0
CMP
S44a
44a
Hall
Element
40b
S40b
42b
CMP
S44b
44b
S80a
80a
S80b
80b
80c
80d
OSC
OSC
Memory
Temp. Sensor
GND
GND

FIG. 1B

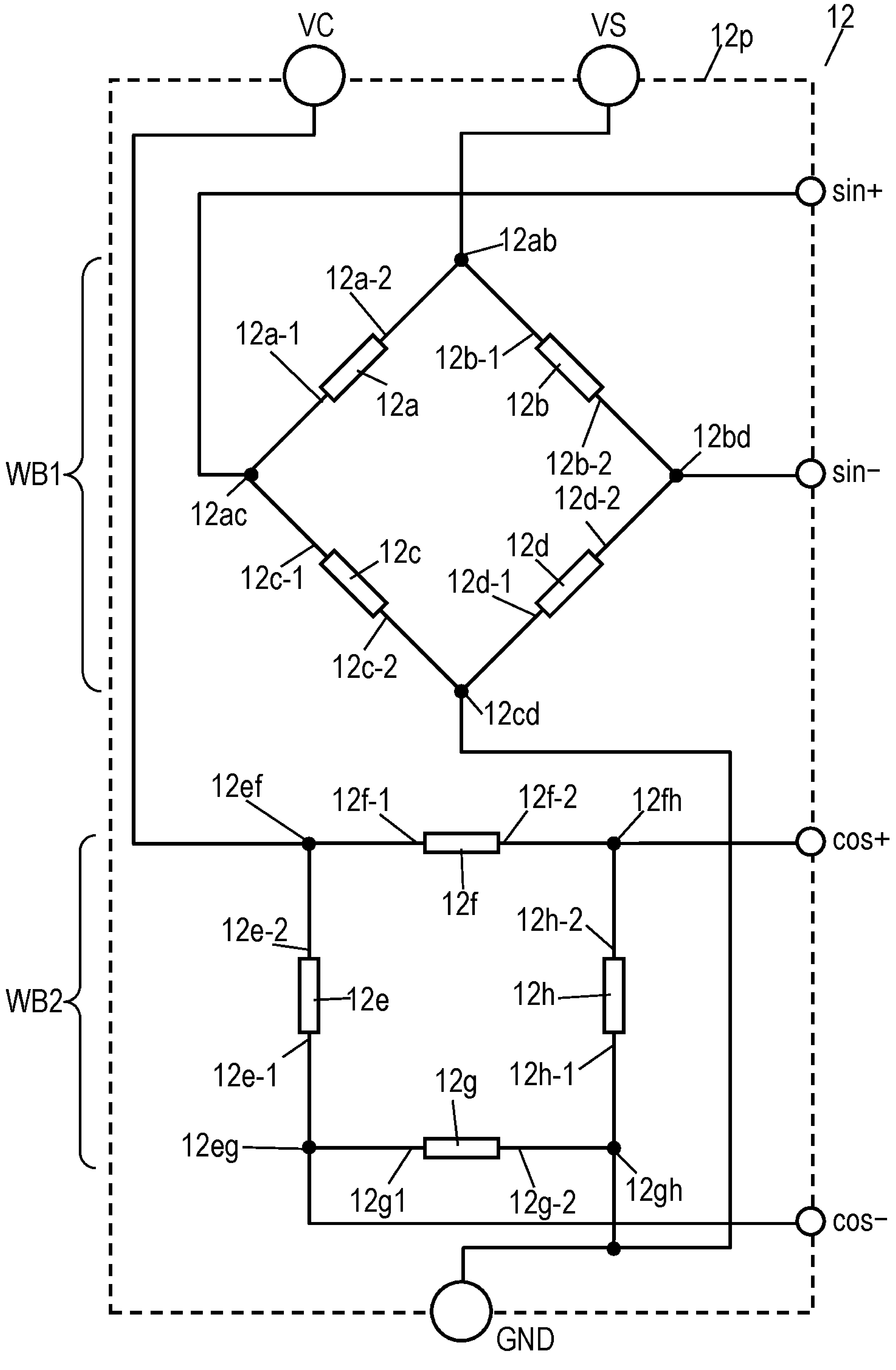

VC
VS
12p
12
sin+
12ab
12a-2
12a-1
12b-1
12a
12b
12bd
12b-2
WB1
sin−
12ac
12d-2
12c
12d
12c-1
12d-1
12c-2
12cd
12ef
12f-1
12f-2
12fh
cos+
12f
12e-2
12h-2
WB2
12e
12h
12e-1
12h-1
12g
12eg
12g1
12g-2
12gh
cos−
GND

FIG. 2A

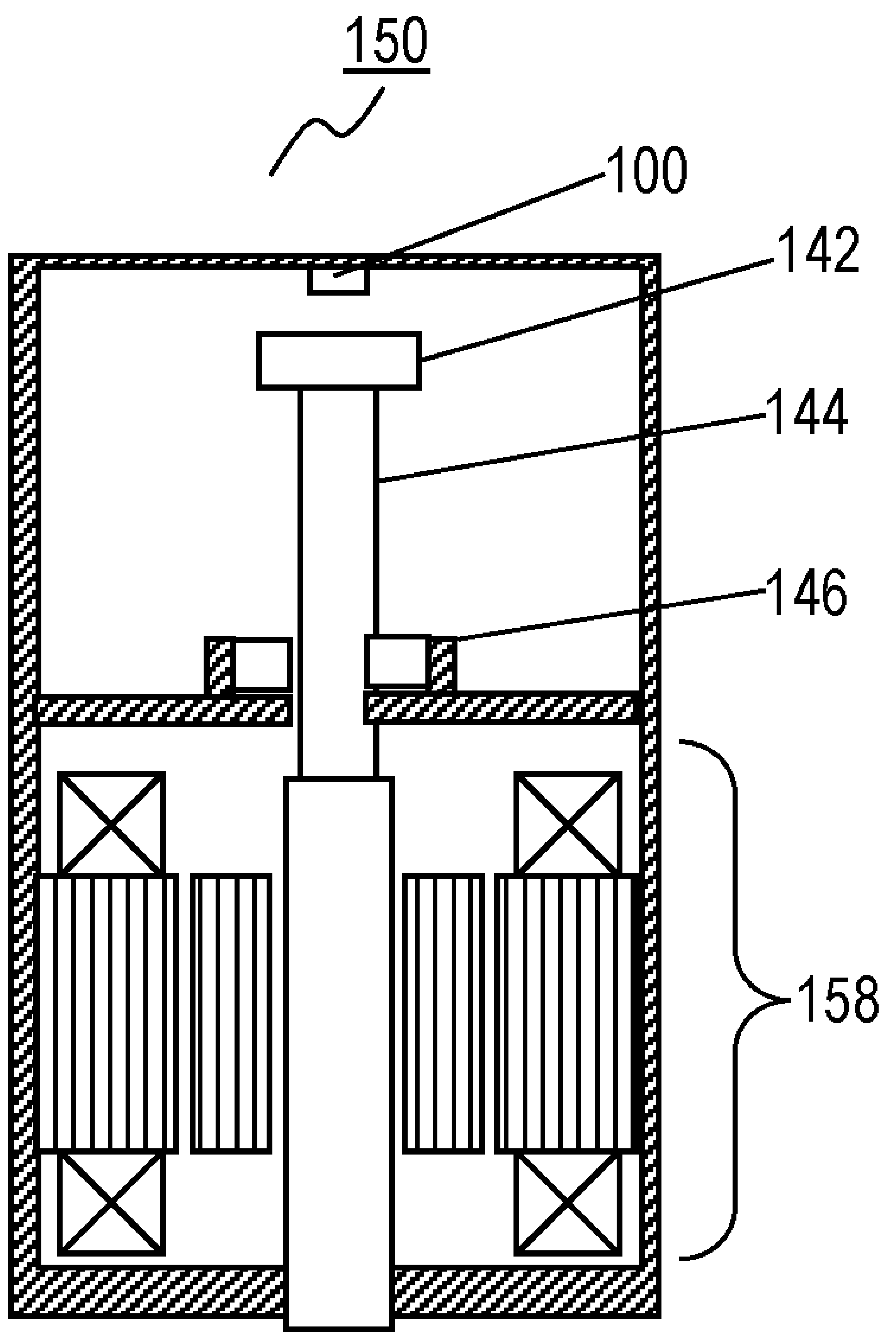


FIG. 2B

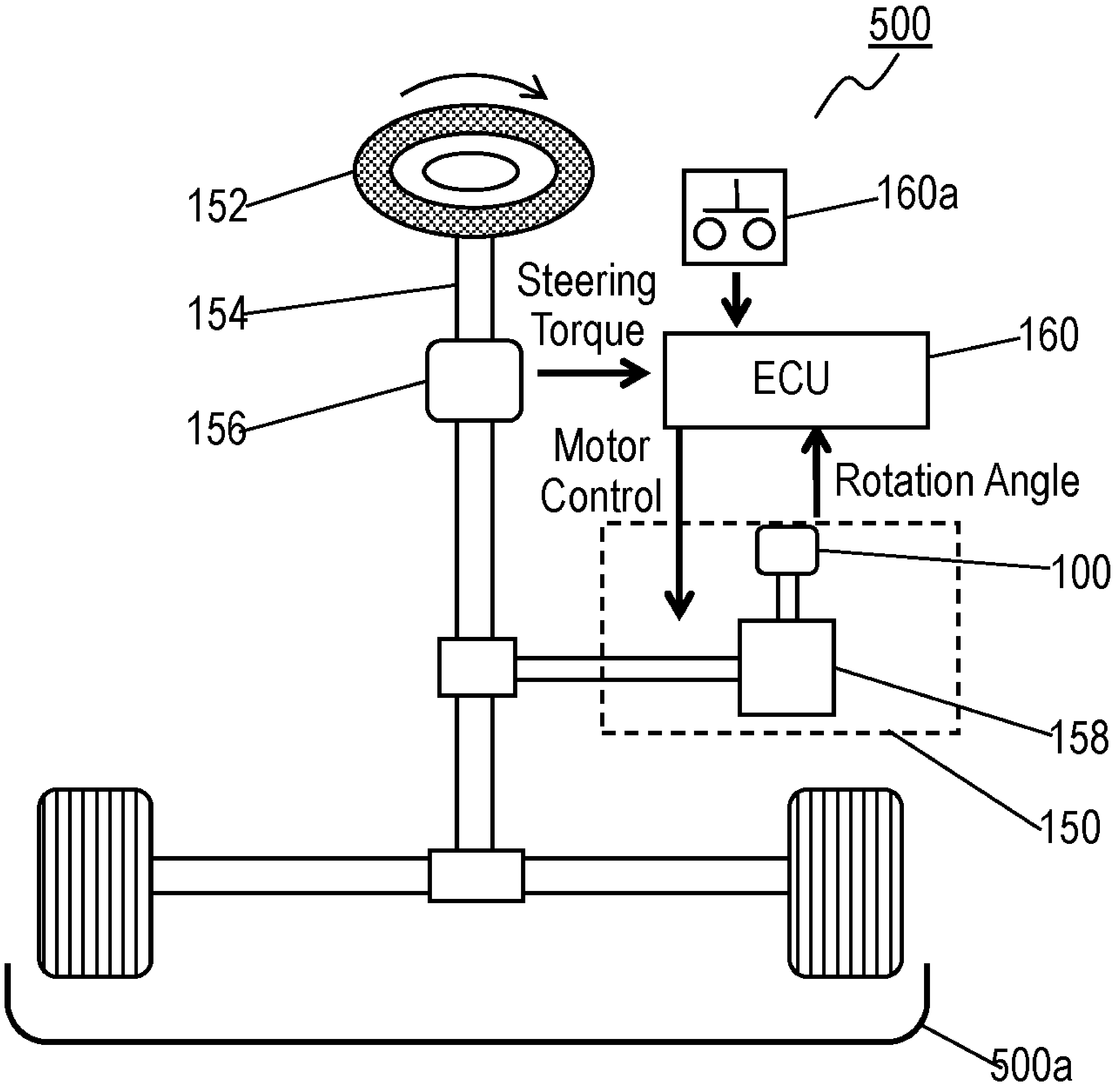

500
152
160a
154
Steering Torque
160
ECU
156
Motor Control
Rotation Angle
100
158
150
500a

FIG. 3

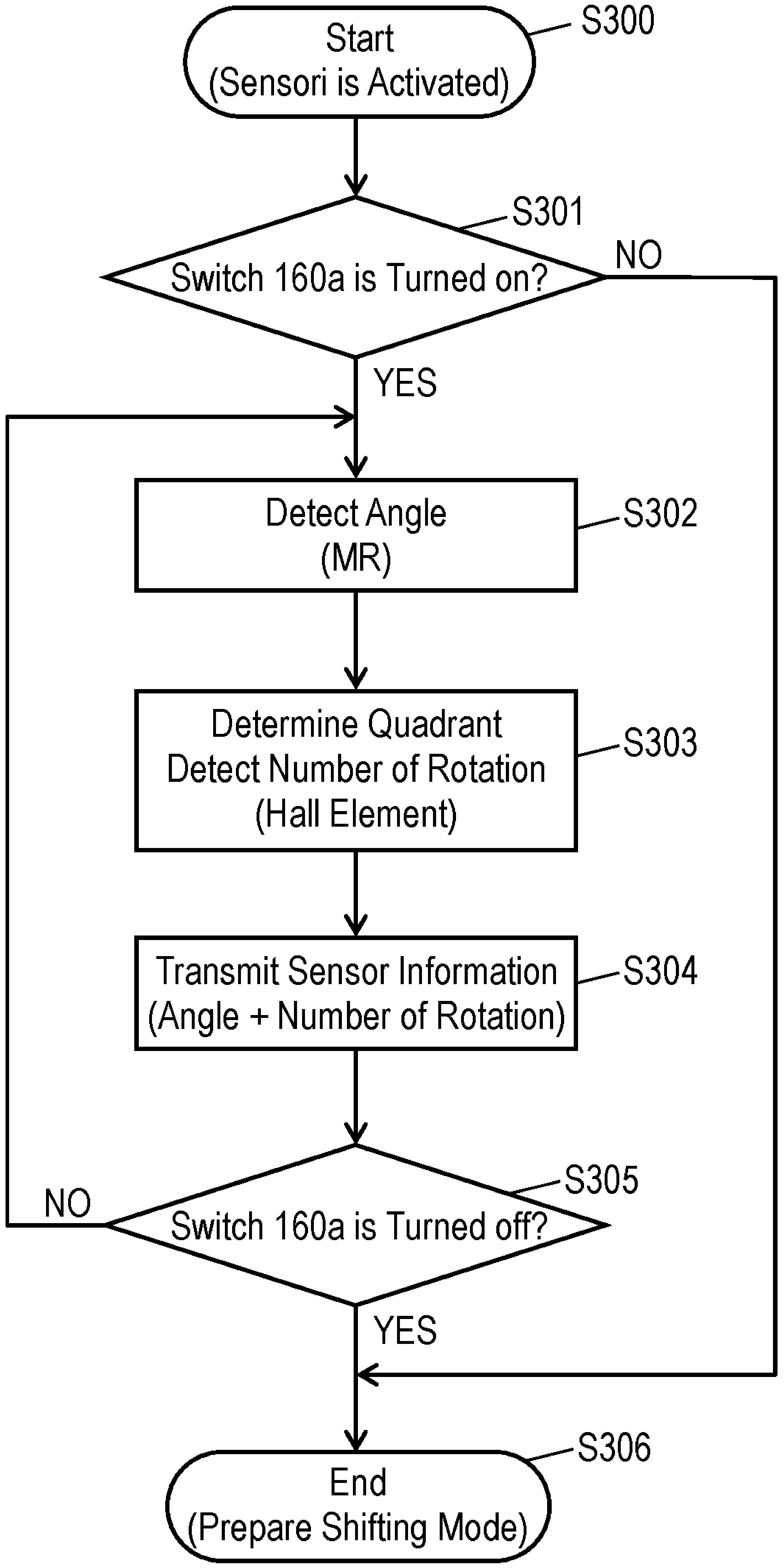

Start
(Sensori is Activated)
S300
S301
Switch 160a is Turned on?
NO
YES
Detect Angle
(MR)
S302
Determine Quadrant
Detect Number of Rotation
(Hall Element)
S303
Transmit Sensor Information
(Angle + Number of Rotation)
S304
S305
NO
Switch 160a is Turned off?
YES
S306
End
(Prepare Shifting Mode)

FIG. 4

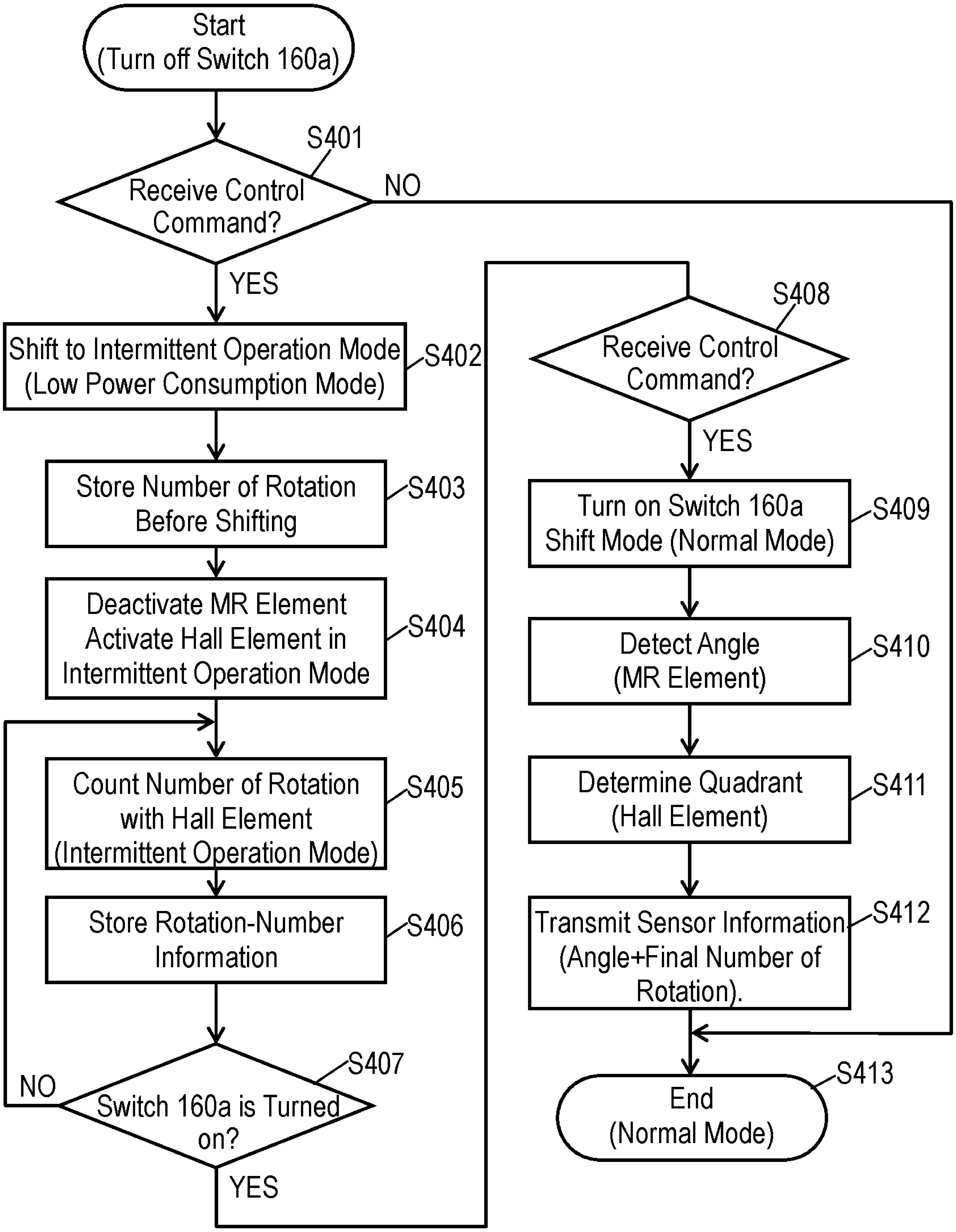

Start
(Turn off Switch 160a)
S401
Receive Control Command?
NO
YES
Shift to Intermittent Operation Mode (Low Power Consumption Mode)
S402
Store Number of Rotation Before Shifting
S403
Deactivate MR Element Activate Hall Element in Intermittent Operation Mode
S404
Count Number of Rotation with Hall Element (Intermittent Operation Mode)
S405
Store Rotation-Number Information
S406
Switch 160a is Turned on?
S407
NO
YES
S408
Receive Control Command?
YES
Turn on Switch 160a Shift Mode (Normal Mode)
S409
Detect Angle (MR Element)
S410
Determine Quadrant (Hall Element)
S411
Transmit Sensor Information (Angle+Final Number of Rotation).
S412
End
(Normal Mode)
S413

FIG. 5

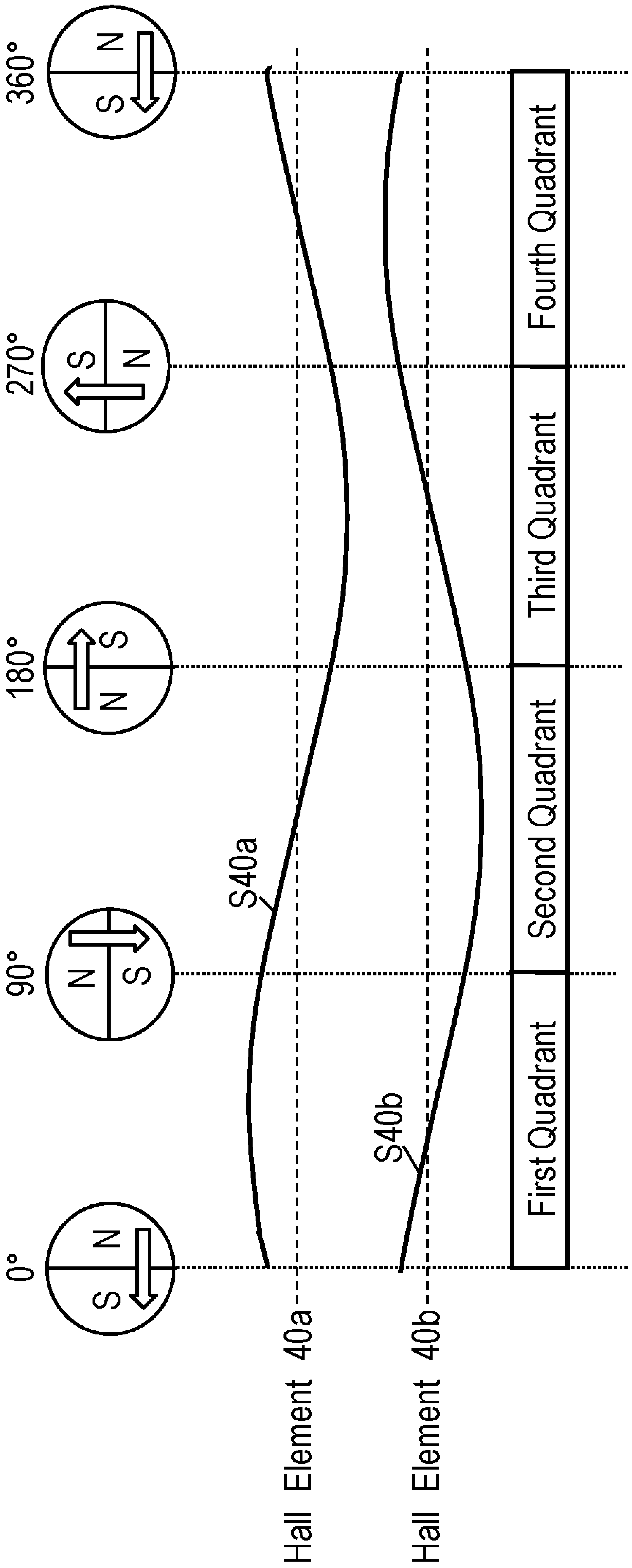

0°
90°
180°
270°
360°
S
N
S40a
S40b
Hall Element 40a
Hall Element 40b
First Quadrant
Second Quadrant
Third Quadrant
Fourth Quadrant

FIG. 6

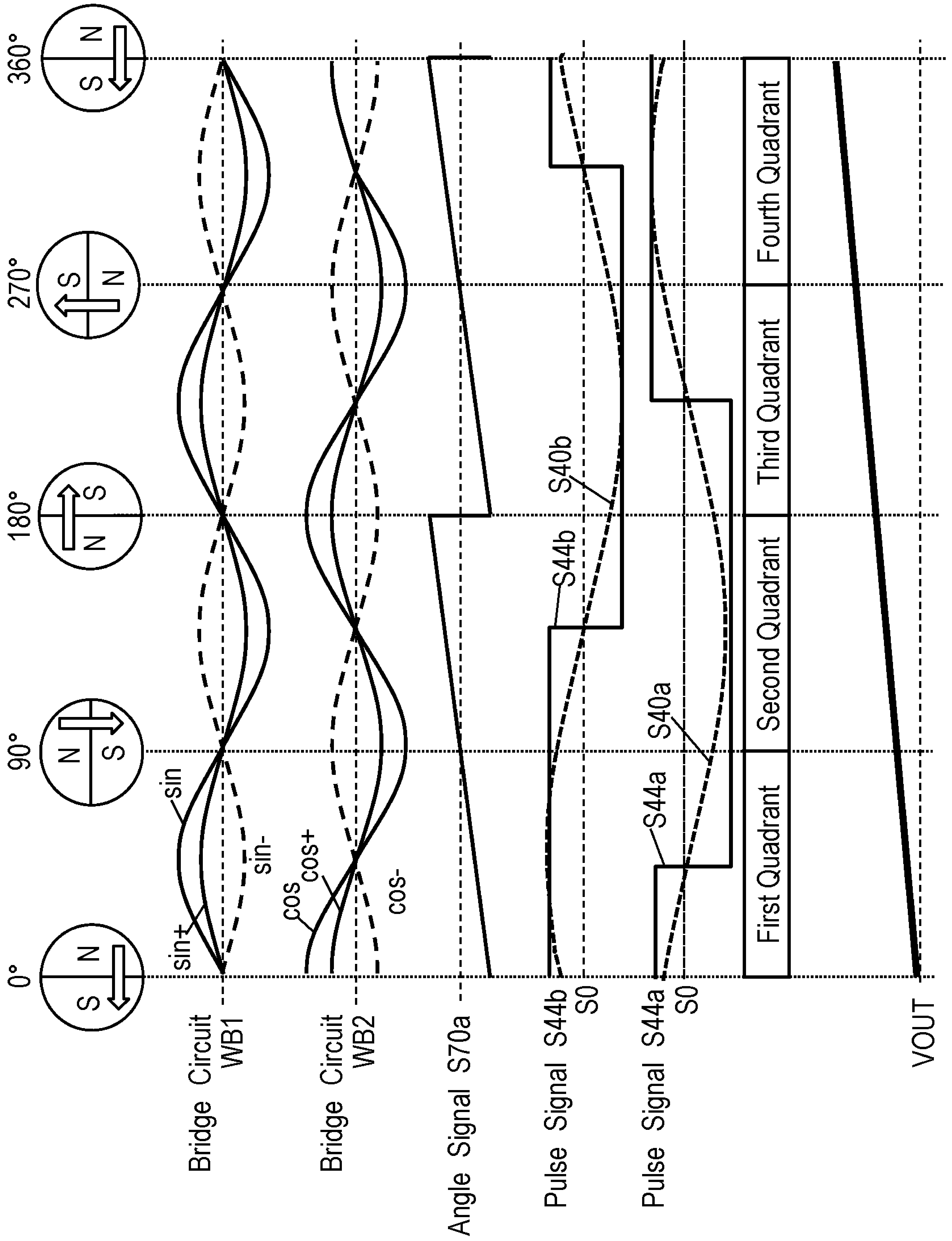

0°
90°
180°
270°
360°
N
S
Bridge Circuit WB1
Bridge Circuit WB2
Angle Signal S70a
Pulse Signal S44b
S0
Pulse Signal S44a
S0
VOUT
sin+
sin
sin-
cos
cos+
cos-
S44a
S40a
S44b
S40b
First Quadrant
Second Quadrant
Third Quadrant
Fourth Quadrant

FIG. 7A

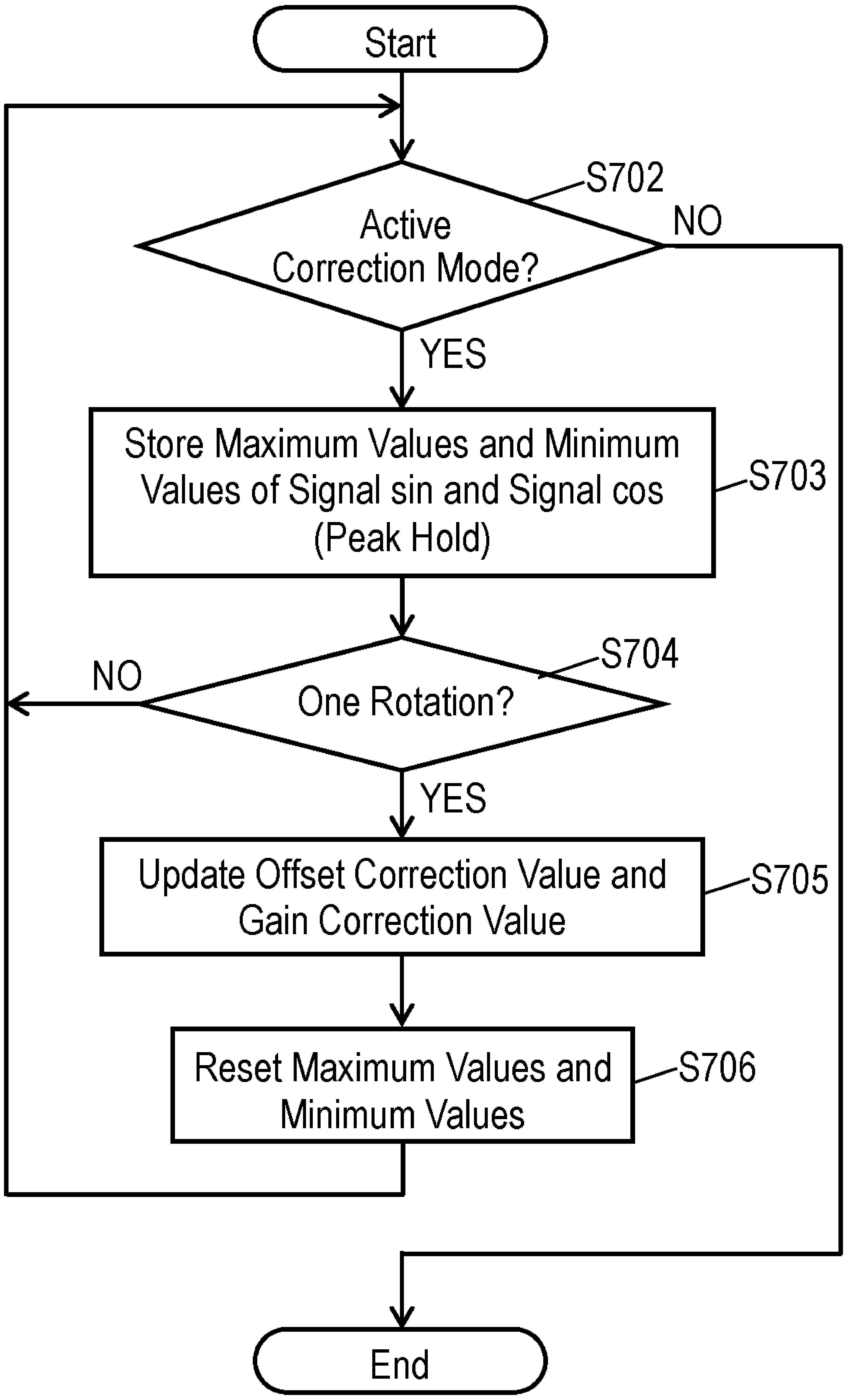

Start
S702
Active Correction Mode?
NO
YES
Store Maximum Values and Minimum Values of Signal sin and Signal cos (Peak Hold)
S703
S704
NO
One Rotation?
YES
Update Offset Correction Value and Gain Correction Value
S705
Reset Maximum Values and Minimum Values
S706
End

FIG. 7B

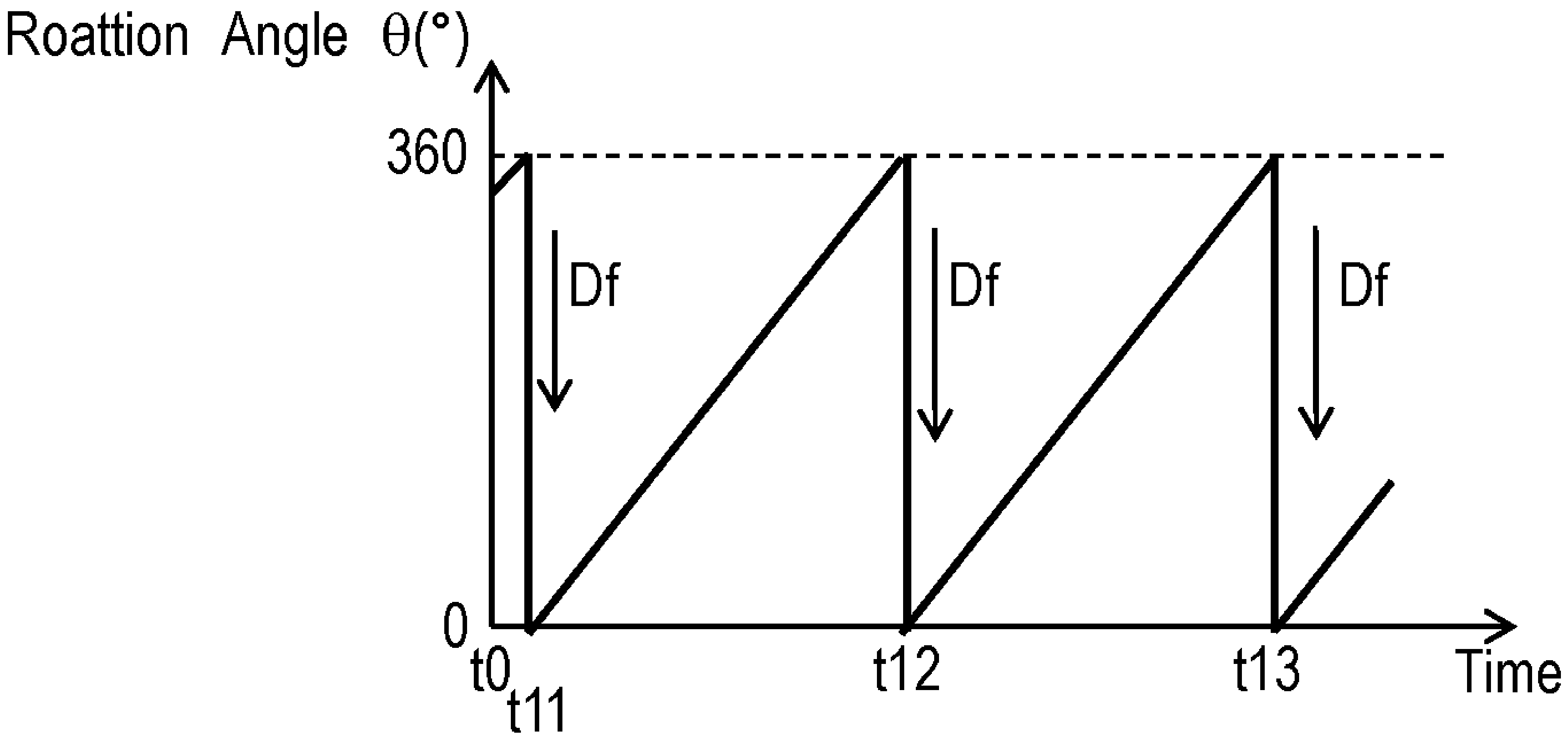
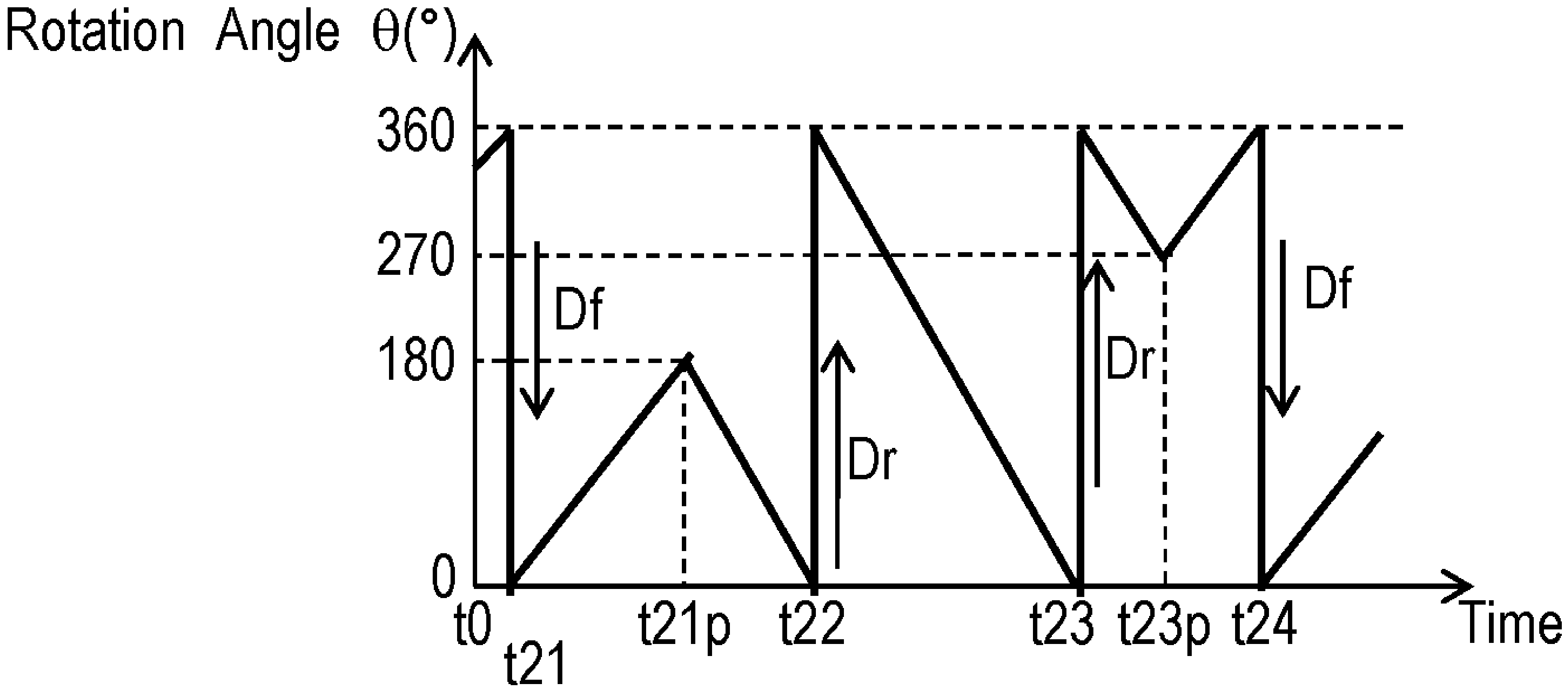

Roattion Angle θ(°)
360
0
Df
Df
Df
t0
t11
t12
t13
Time

FIG. 7C


Rotation Angle θ(°)
360
270
180
0
Df
Dr
Dr
Df
t0
t21
t21p
t22
t23
t23p
t24
Time

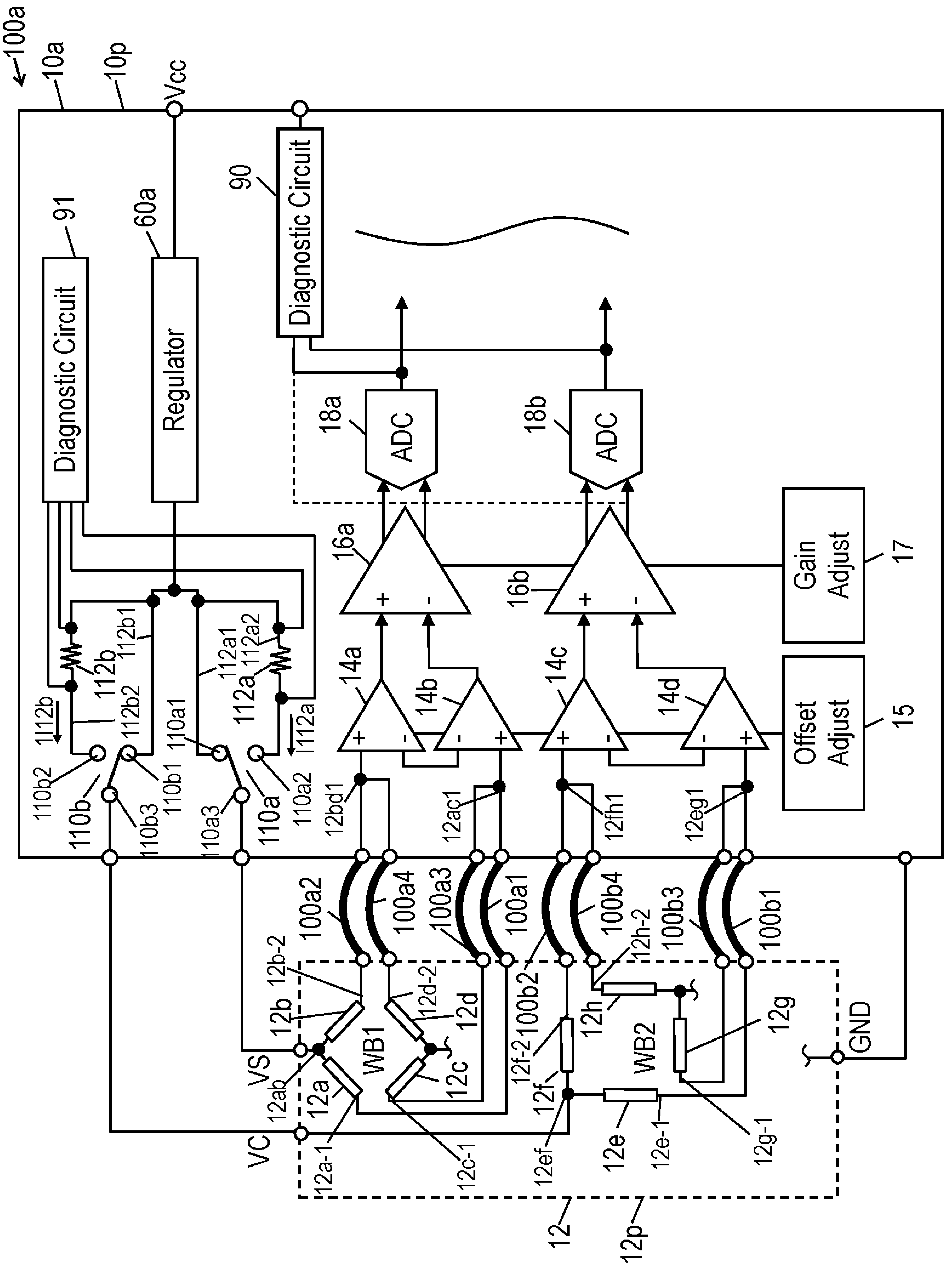

100a
10a
10p
Vcc
91
Diagnostic Circuit
60a
Regulator
90
Diagnostic Circuit
18a
ADC
18b
ADC
16a
16b
17
Gain Adjust
15
Offset Adjust
14a
14b
14c
14d
112b1
112b
112b2
I112b
112a1
112a2
112a
I112a
110a1
110b2
110b1
110b
110b3
110a3
110a
110a2
12bd1
12ac1
12fh1
12eg1
100a2
100a4
100a3
100a1
100b2
100b4
100b3
100b1
12b-2
12b
12d-2
12d
12c
12a
12ab
VS
VC
WB1
12a-1
12c-1
12f-2
12f
12h-2
12h
WB2
12g
12ef
12e
12e-1
12g-1
GND
12
12p
+
-

FIG. 8

FIG. 9

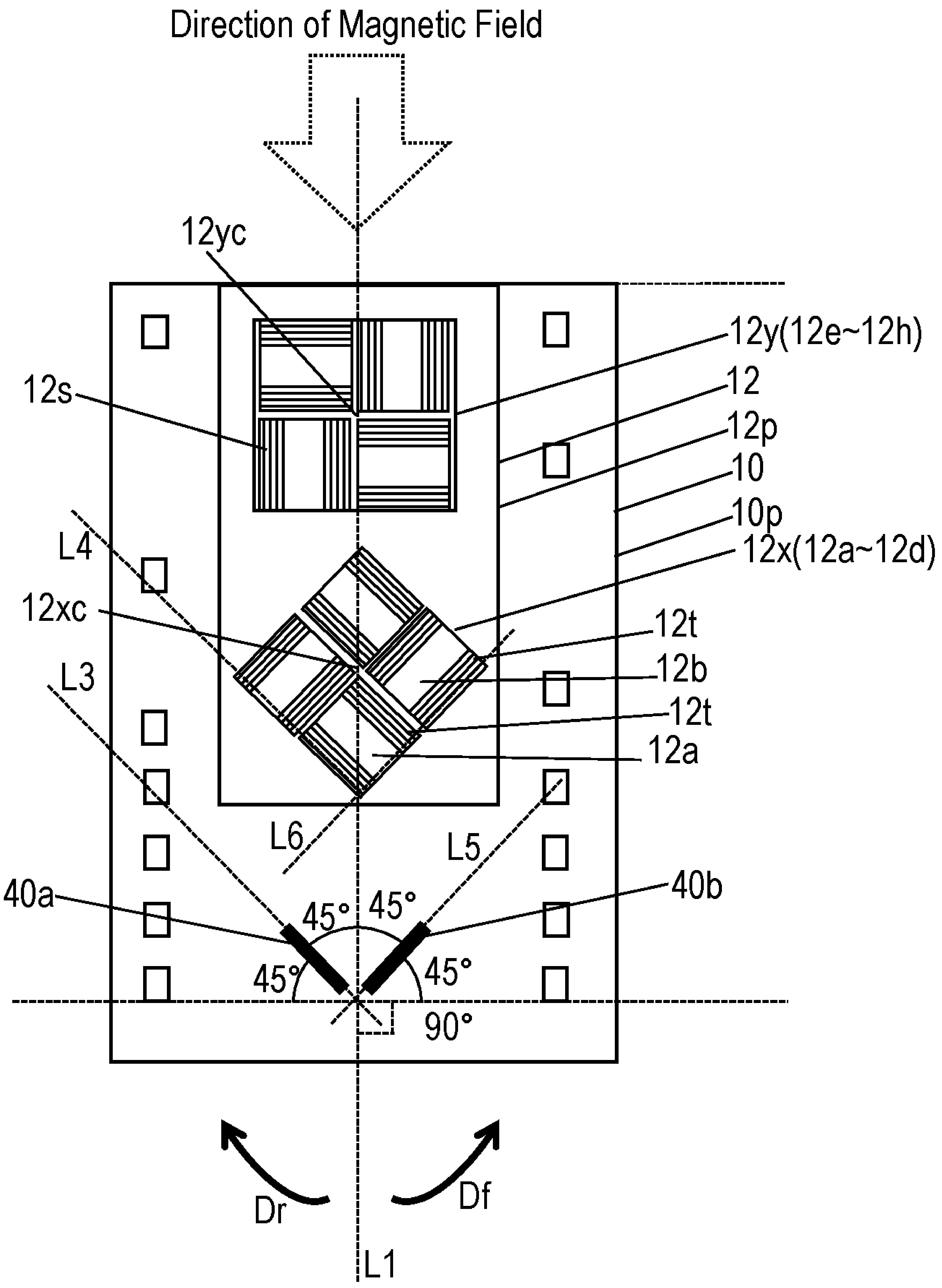

Direction of Magnetic Field
12yc
12y(12e~12h)
12s
12
12p
10
10p
L4
12x(12a~12d)
12xc
12t
12b
L3
12t
12a
L6
L5
40a
45°
45°
40b
45°
45°
90°
Dr
Df
L1

FIG. 10

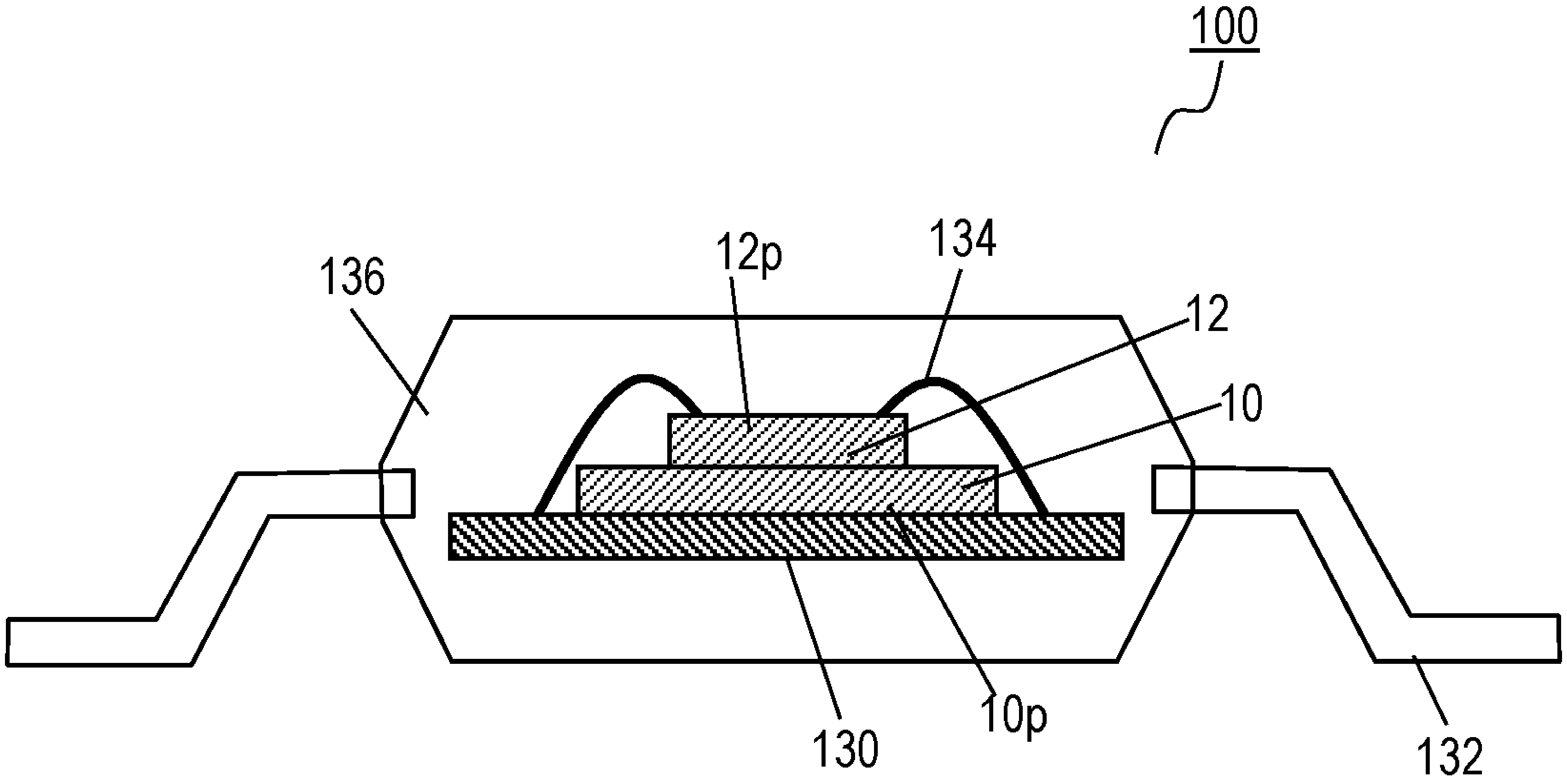


FIG. 11

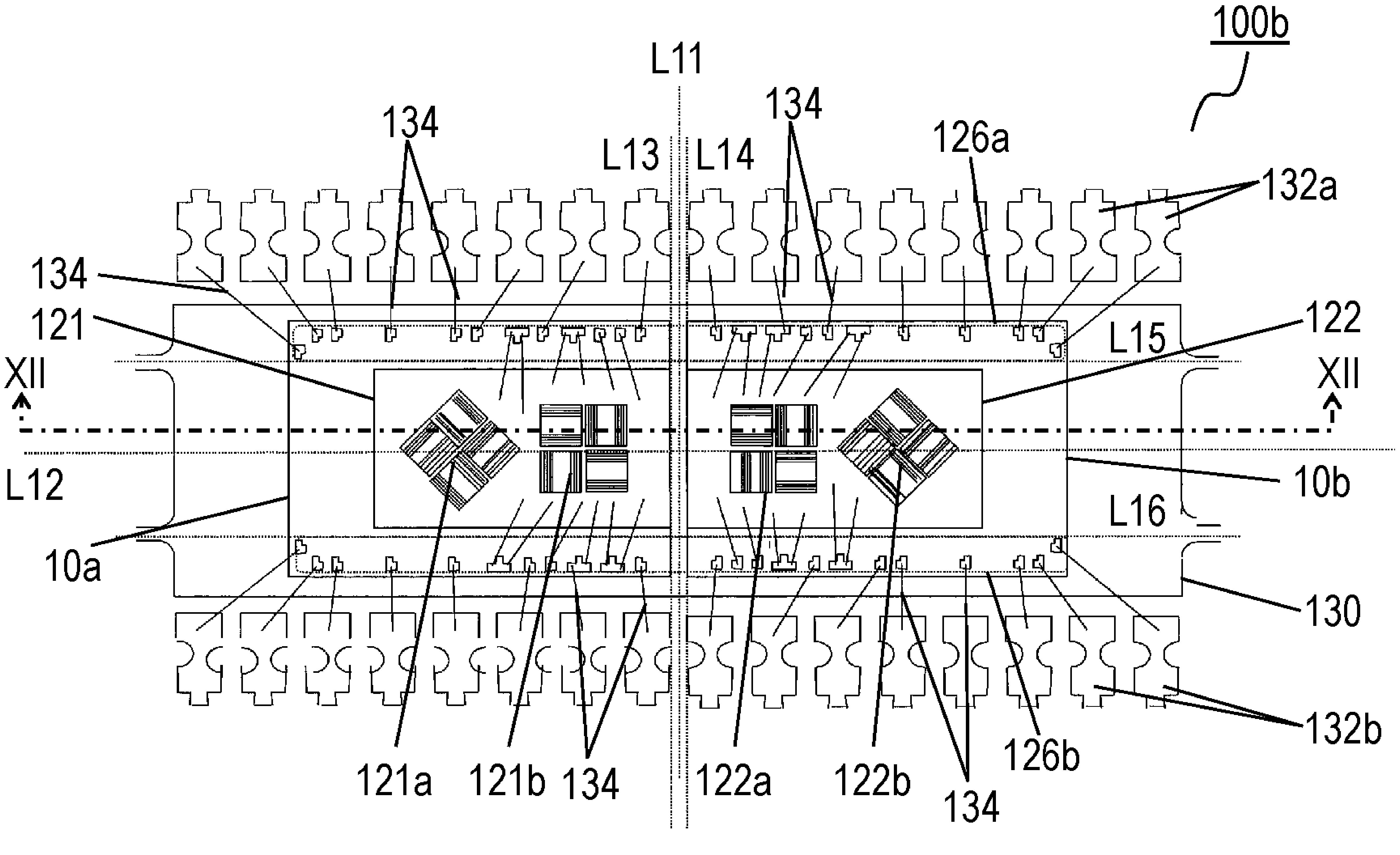

100b
L11
134
L13
L14
134
126a
132a
134
121
122
L15
XII
XII
L12
10b
L16
10a
130
132b
121a
121b
134
122a
122b
126b
134

FIG. 12

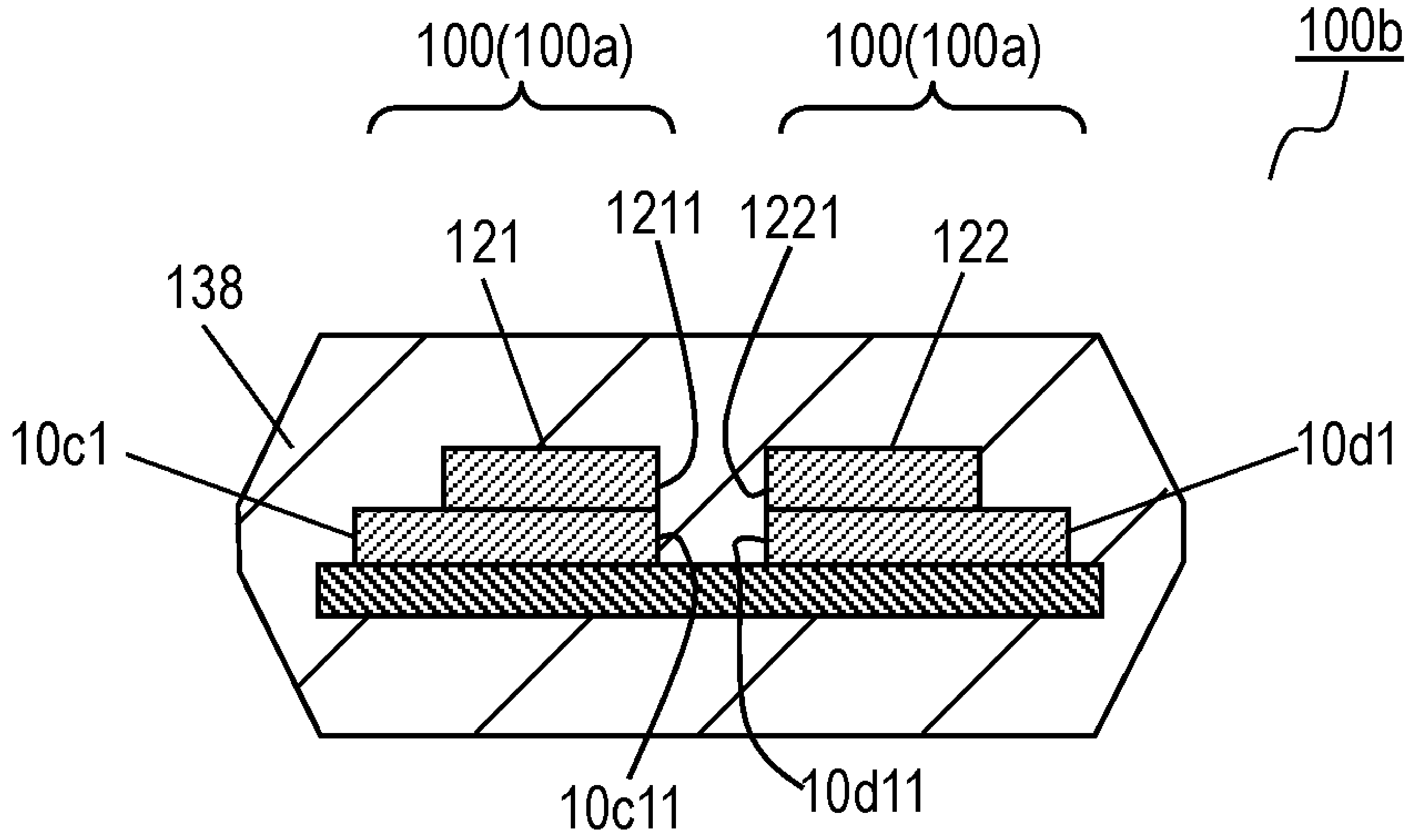

100(100a)
100(100a)
100b
121
1211
1221
122
138
10c1
10d1
10c11
10d11

FIG. 13

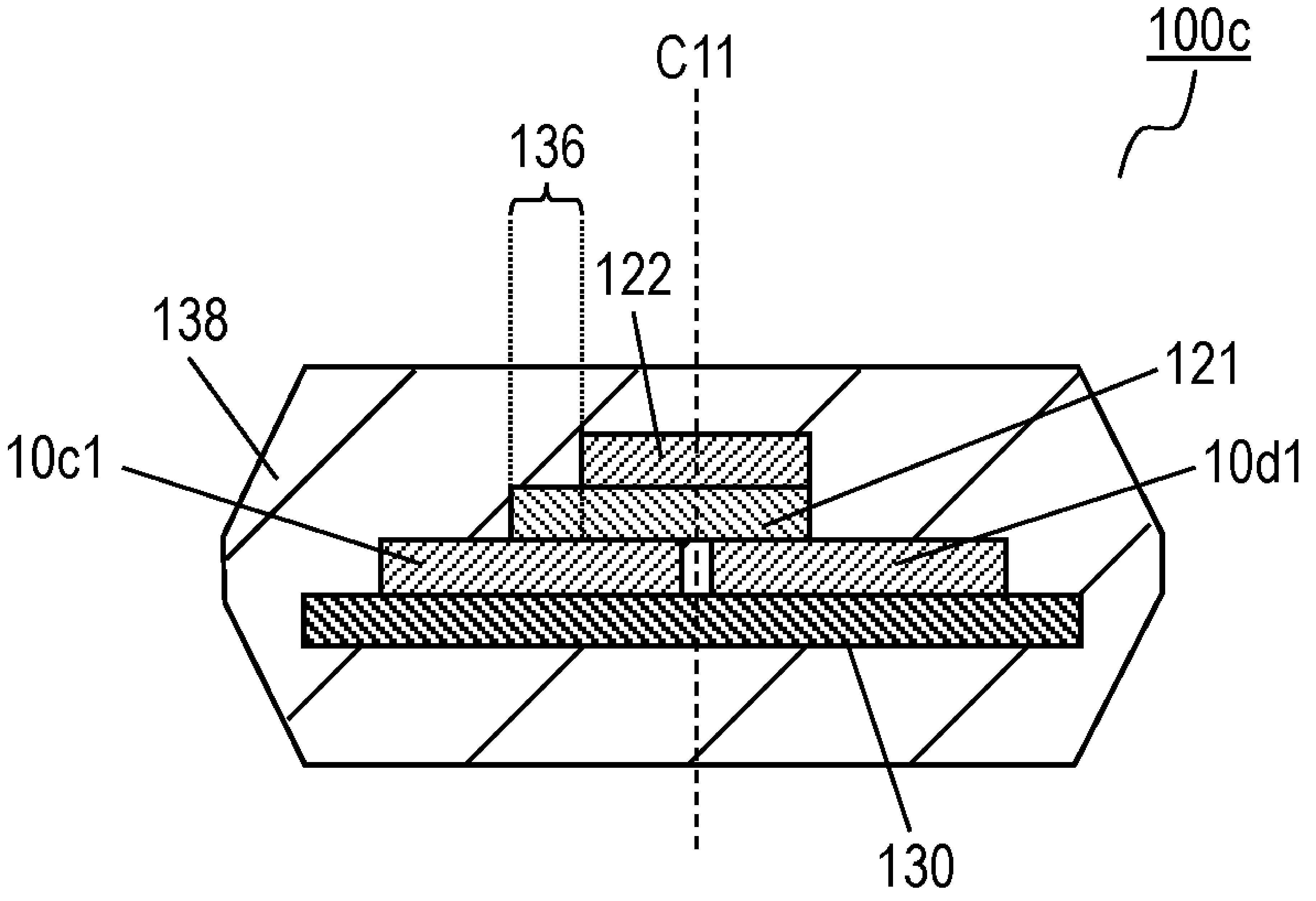

100c
C11
136
122
138
121
10c1
10d1
130

FIG. 14

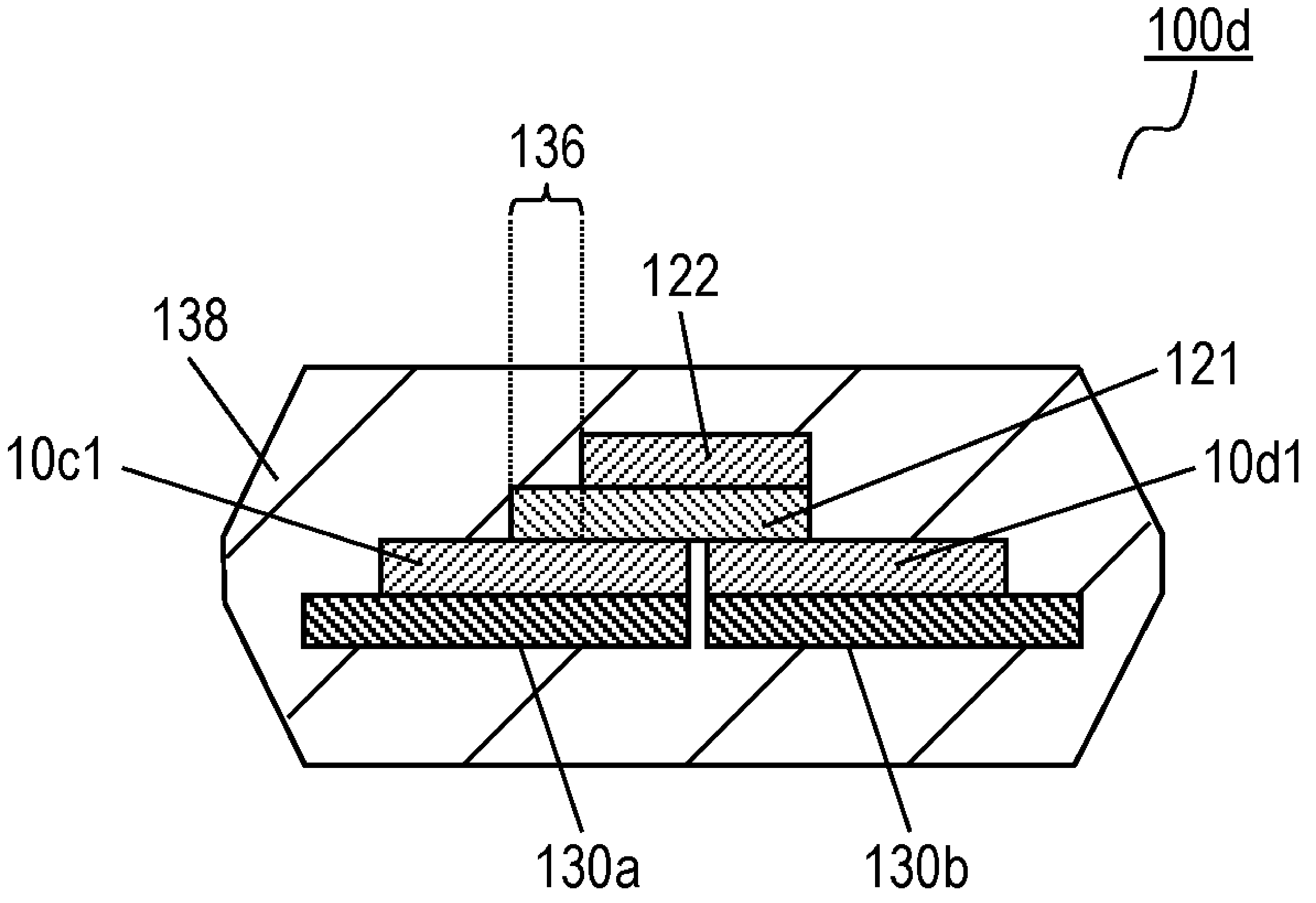

100d
136
122
138
121
10c1
10d1
130a
130b

FIG. 15

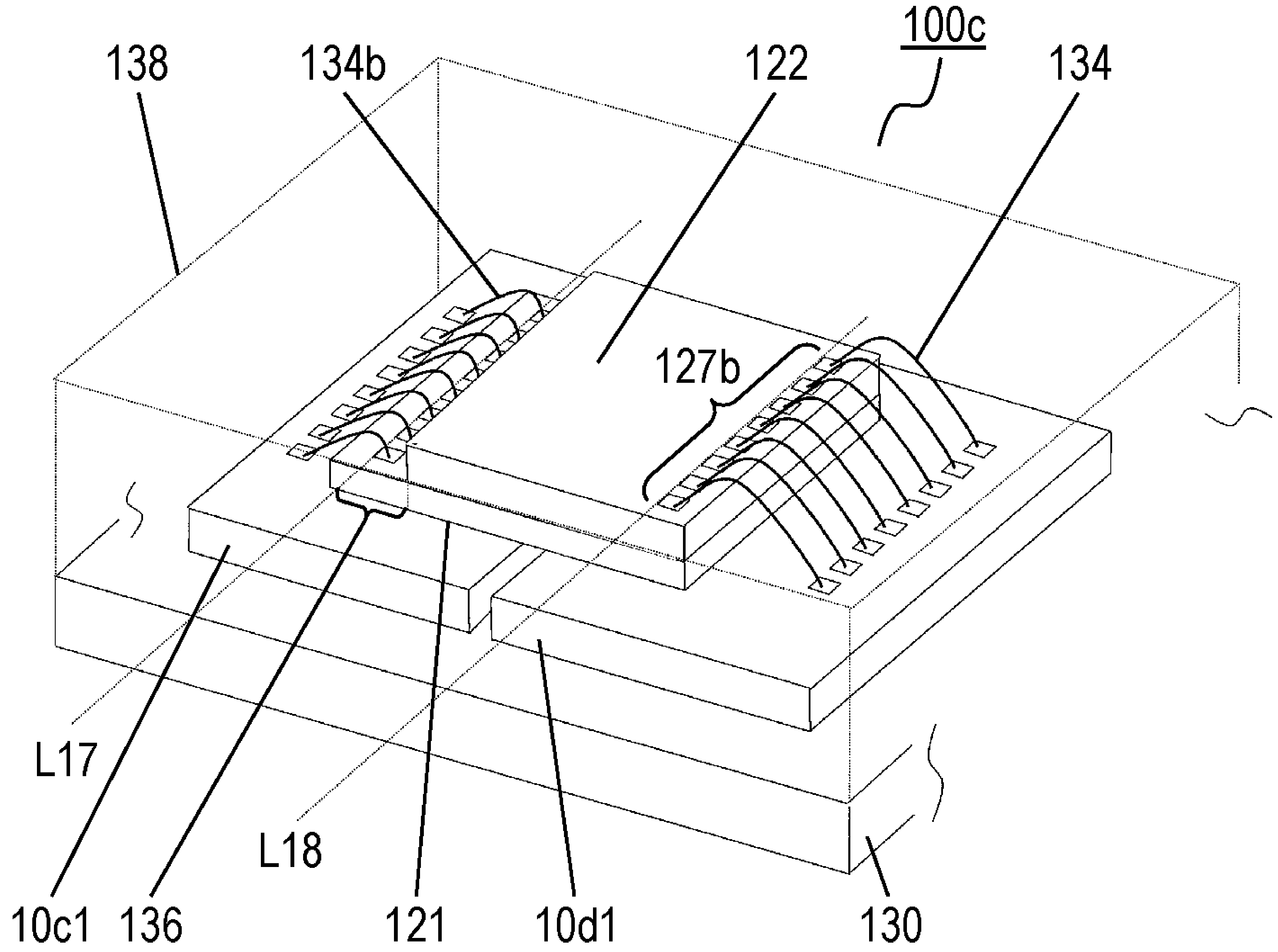

138
134b
122
100c
134
127b
L17
L18
10c1
136
121
10d1
130

FIG. 16

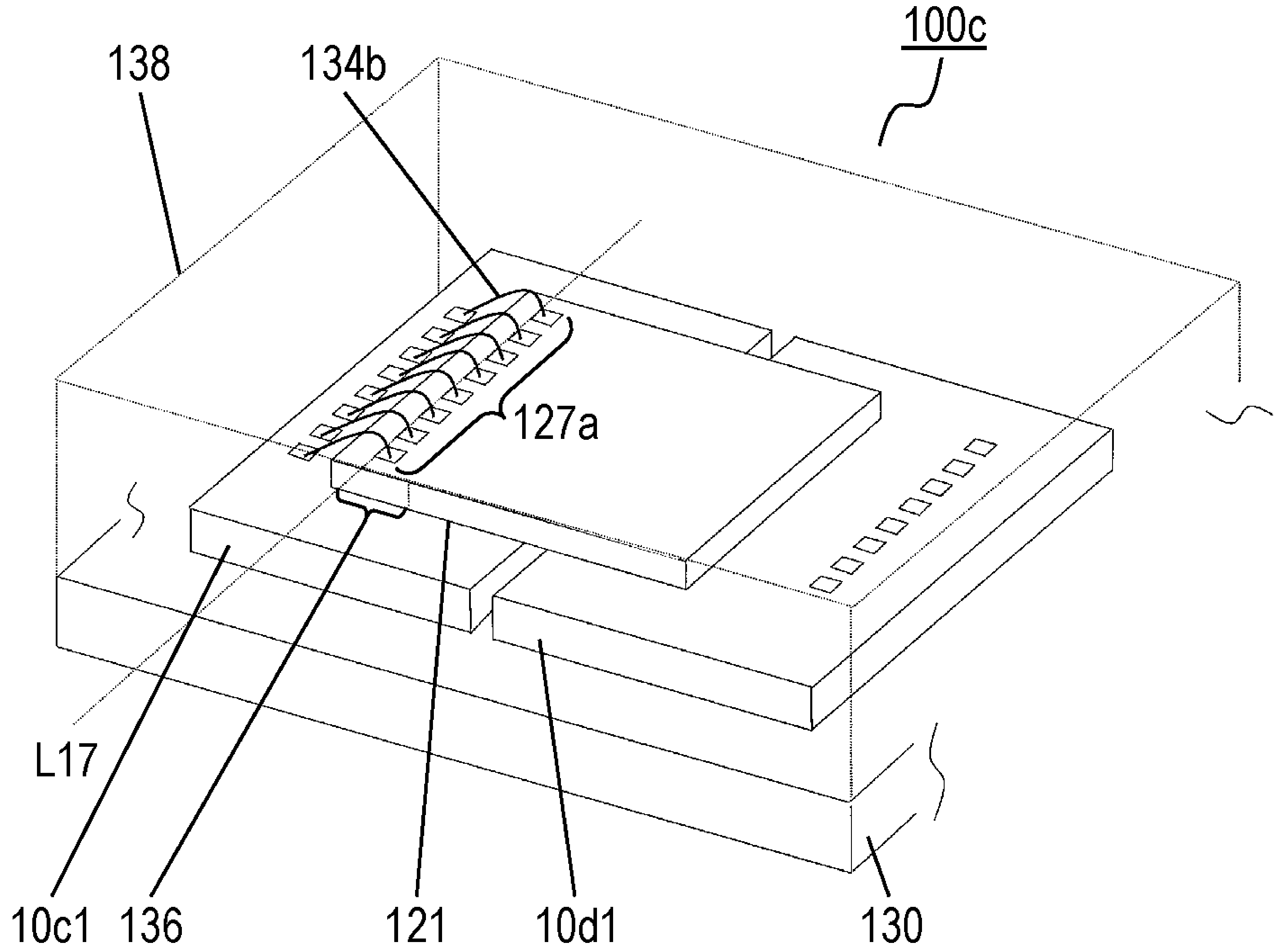

138
134b
100c
127a
L17
10c1
136
121
10d1
130

FIG. 17A

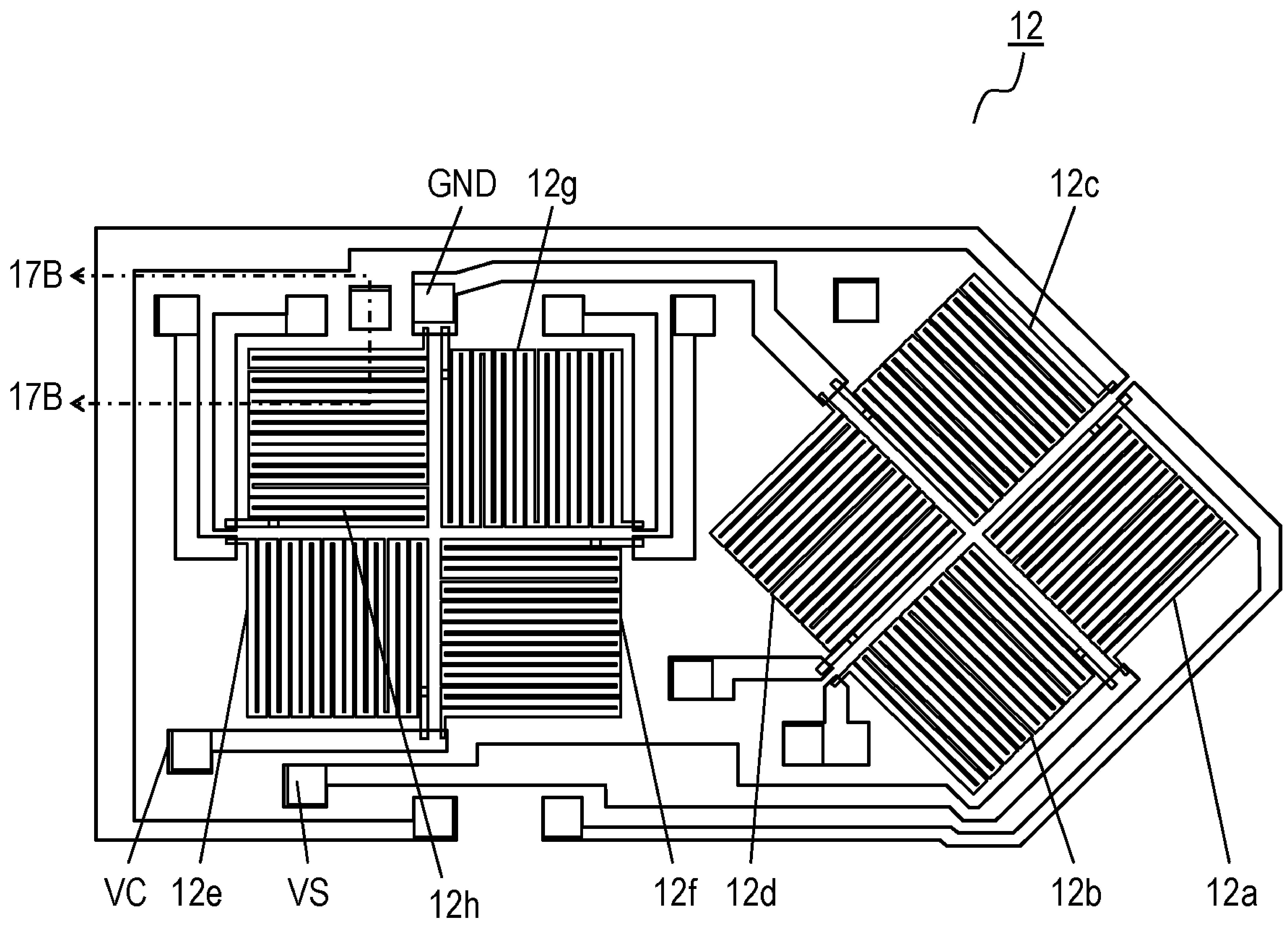


FIG. 17B

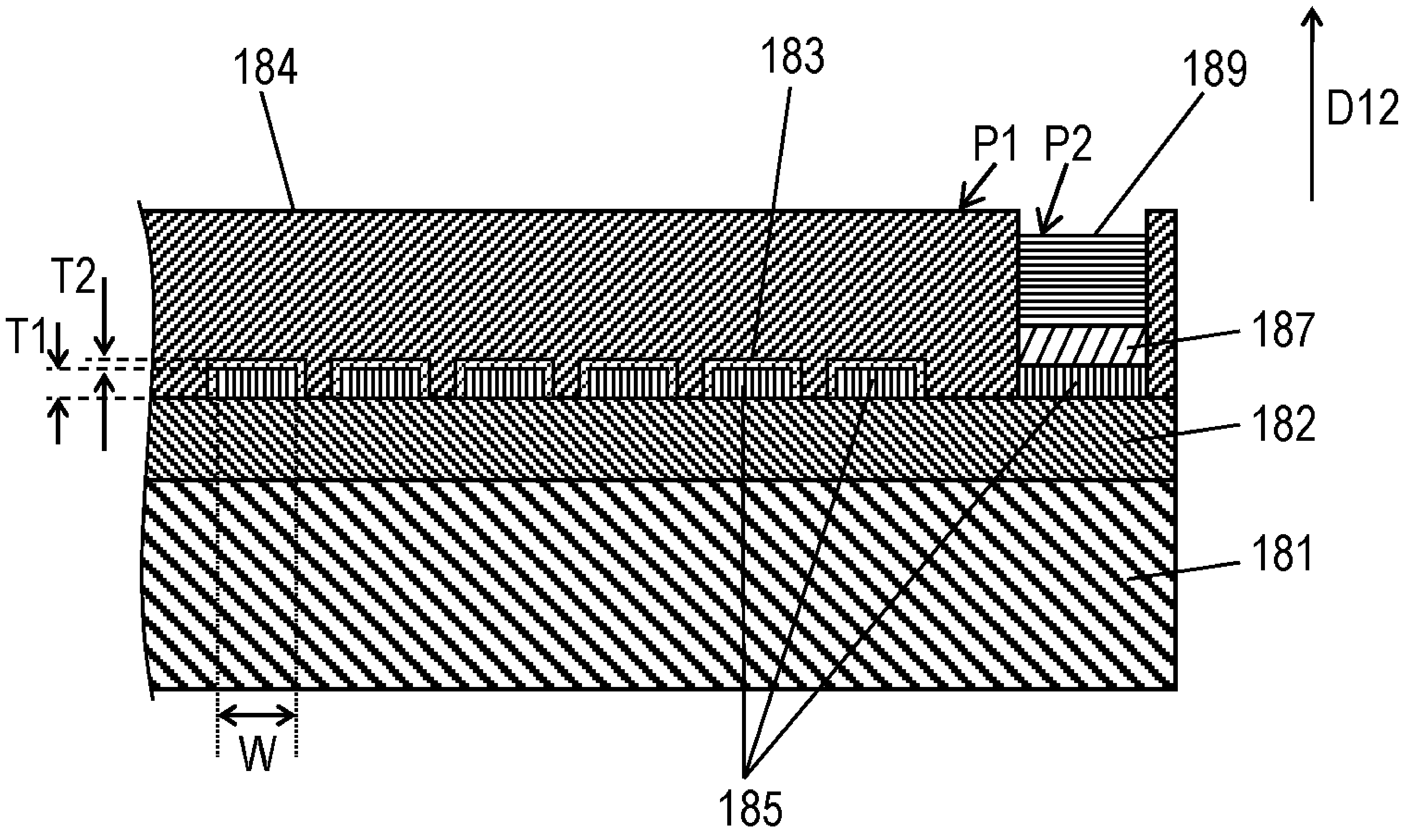


FIG. 18A

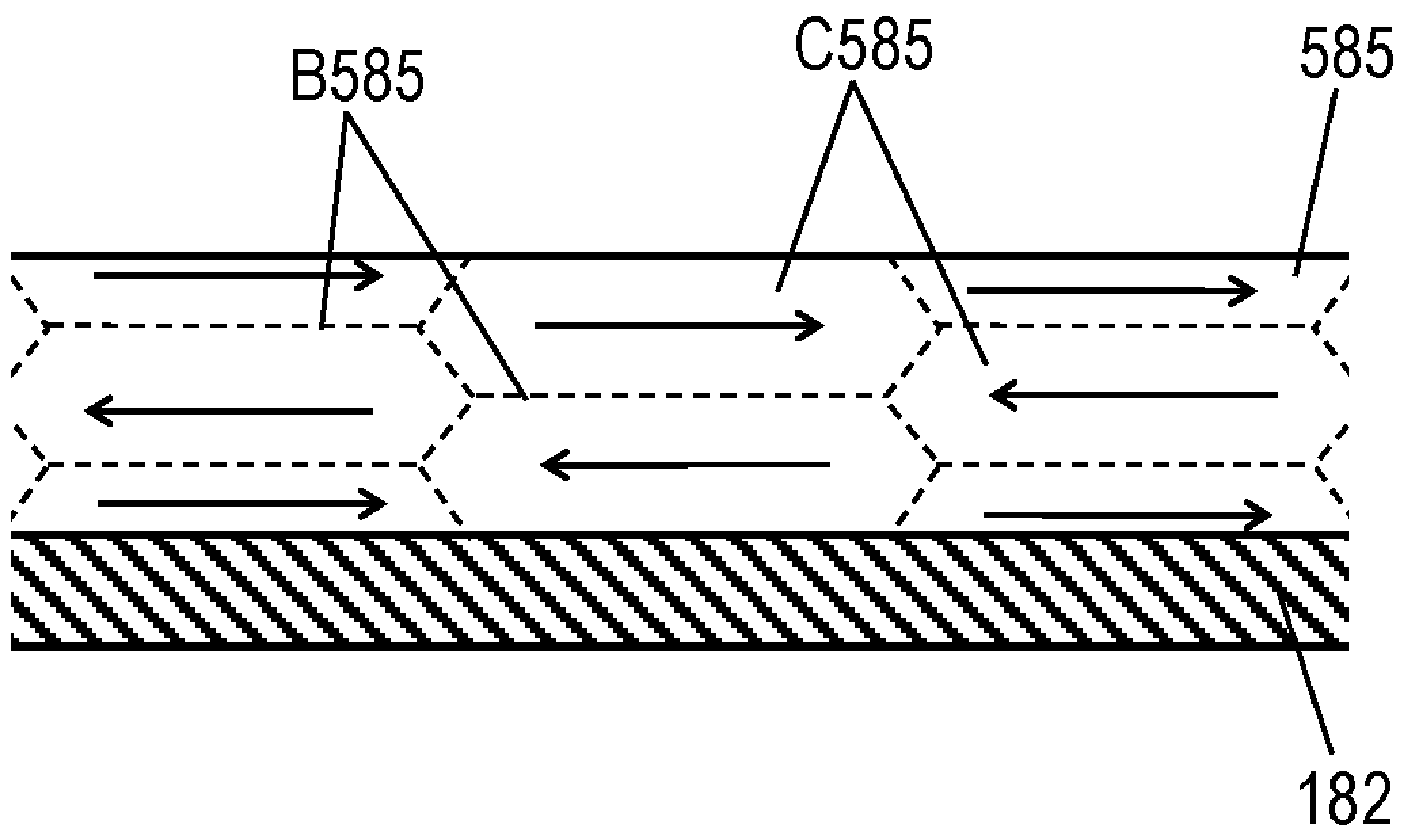


FIG. 18B

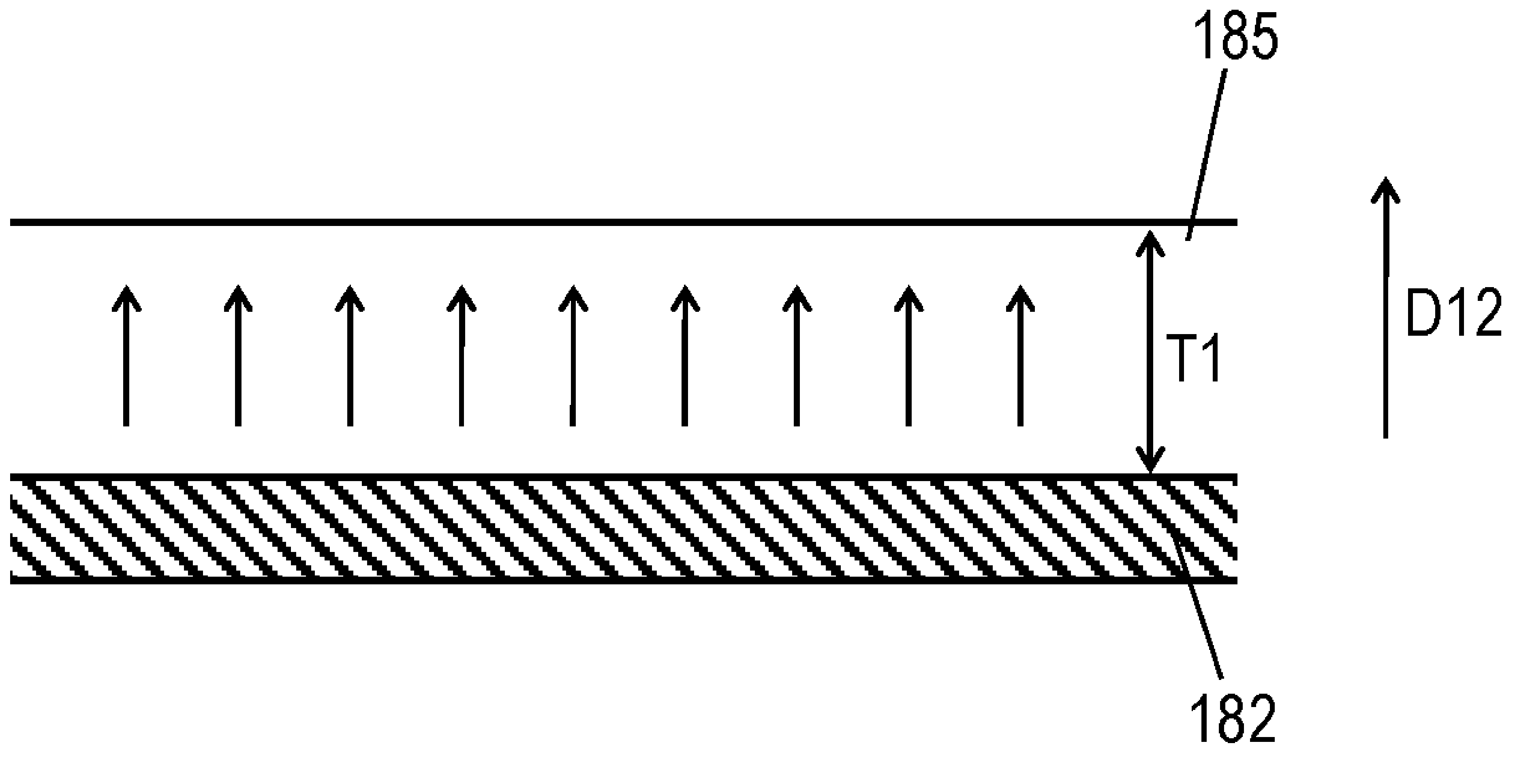


FIG. 19

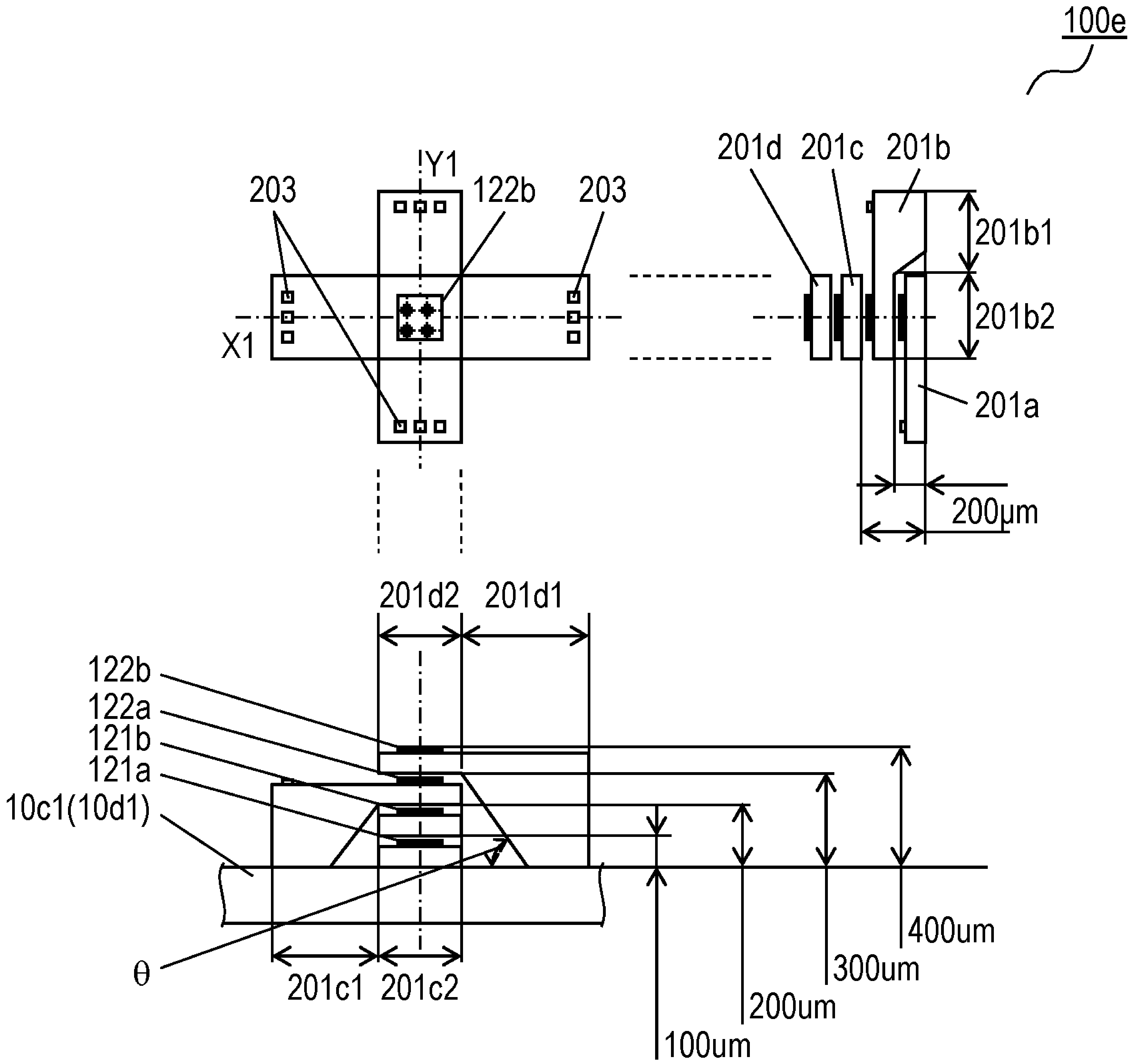

100e
Y1
203
122b
203
X1
201d
201c
201b
201b1
201b2
201a
200μm
201d2
201d1
122b
122a
121b
121a
10c1(10d1)
θ
201c1
201c2
400um
300um
200um
100um

FIG. 20A

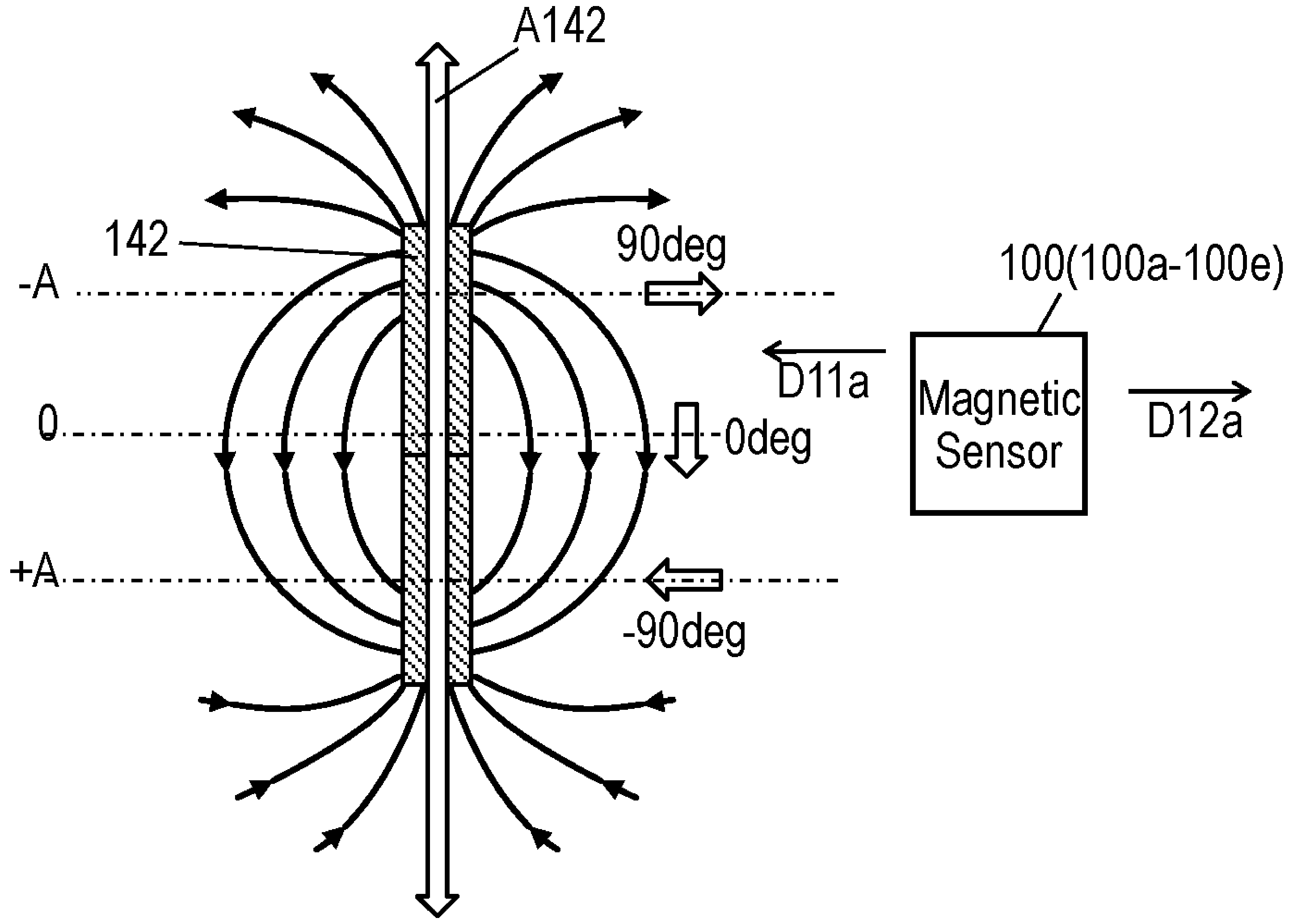


FIG. 20B

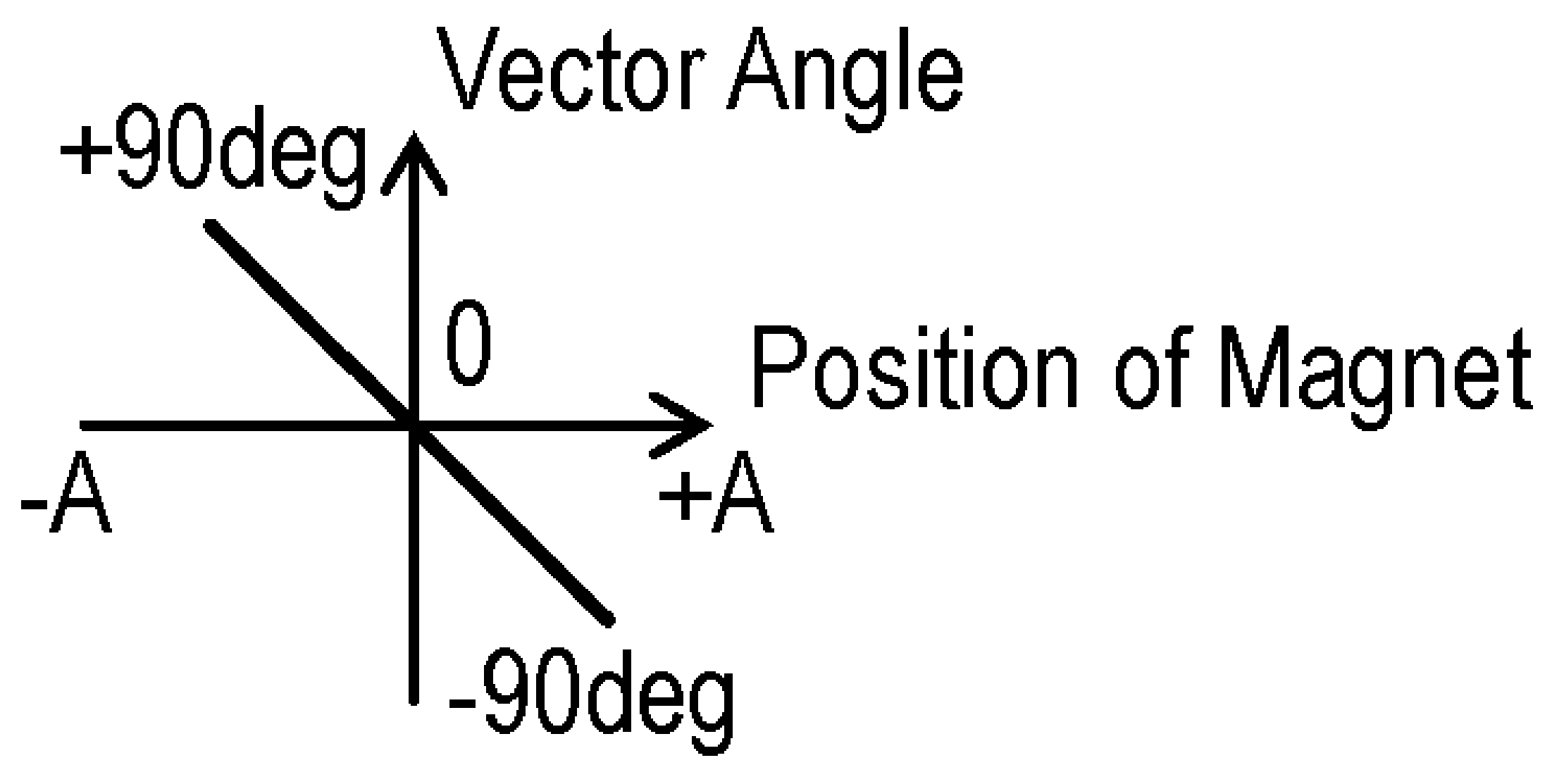


FIG. 20C

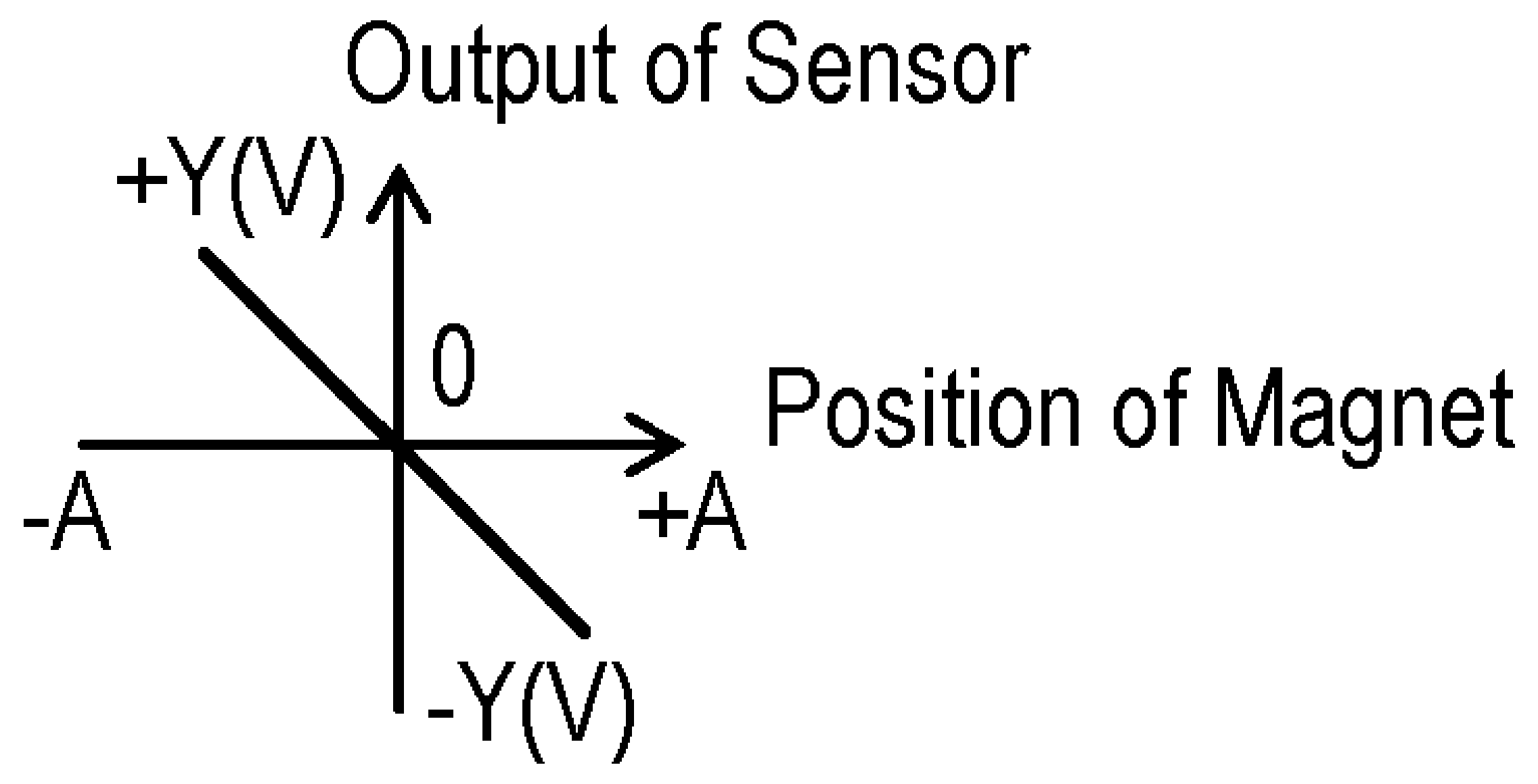


FIG. 21A

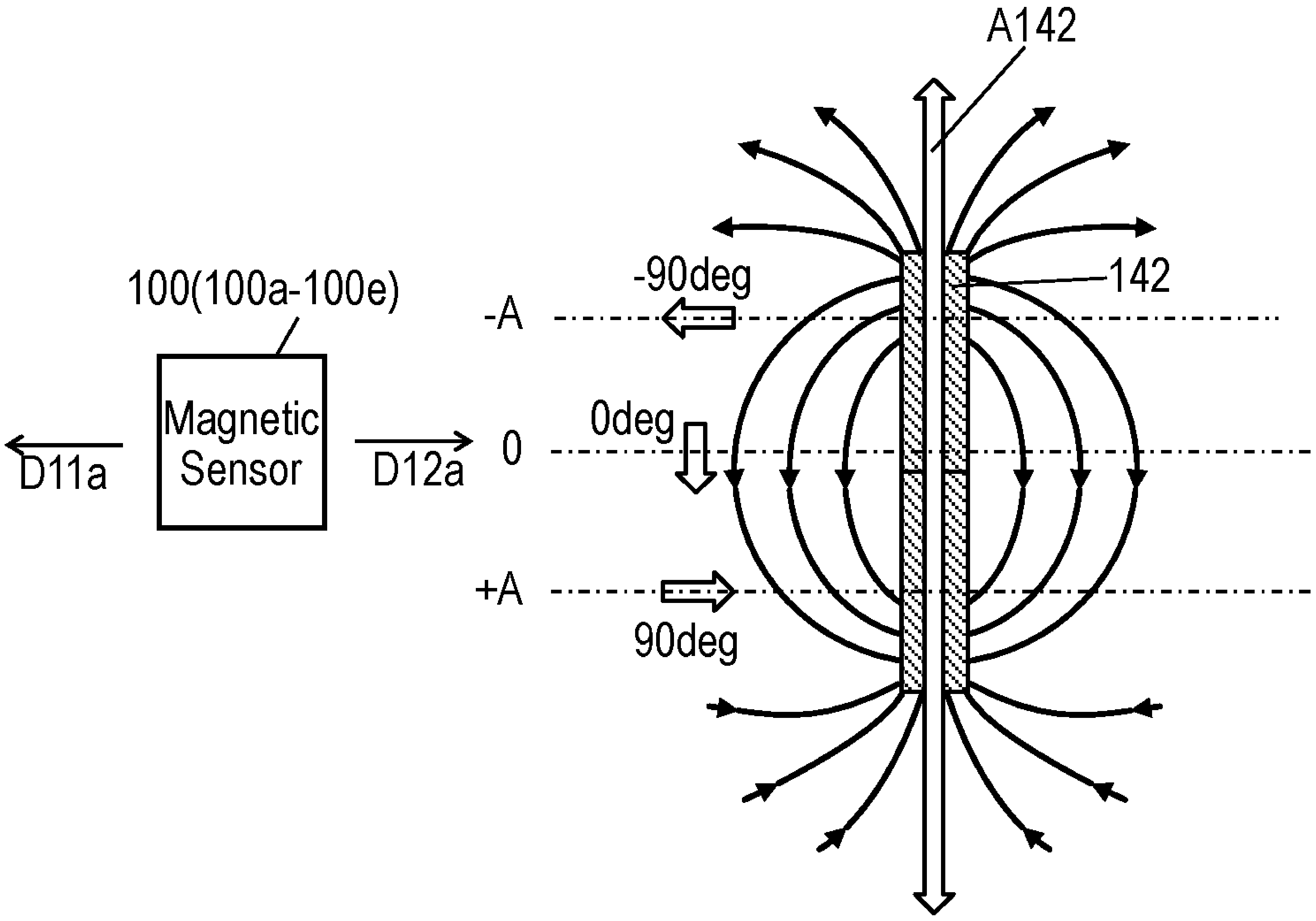


FIG. 21B

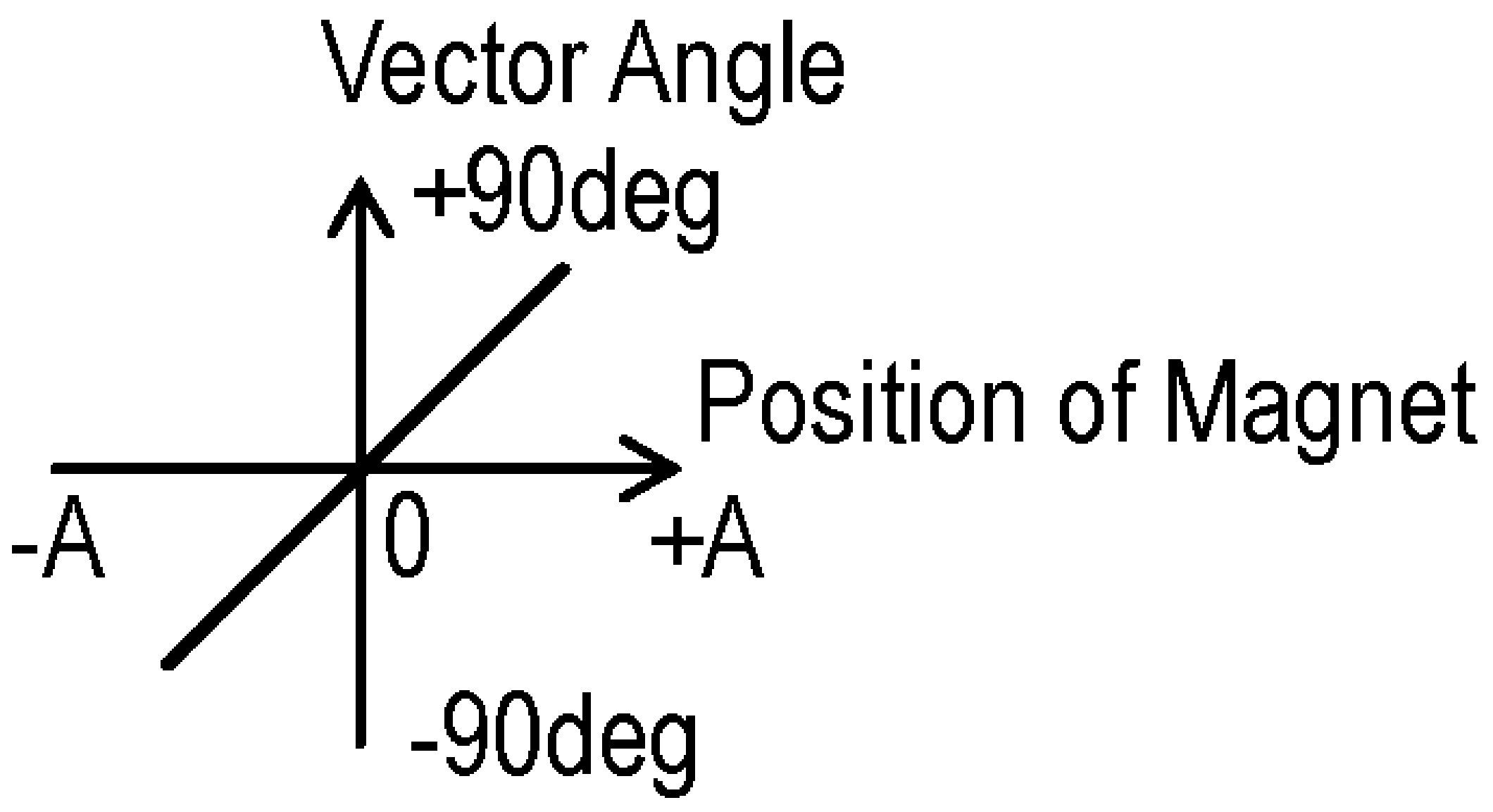


FIG. 21C

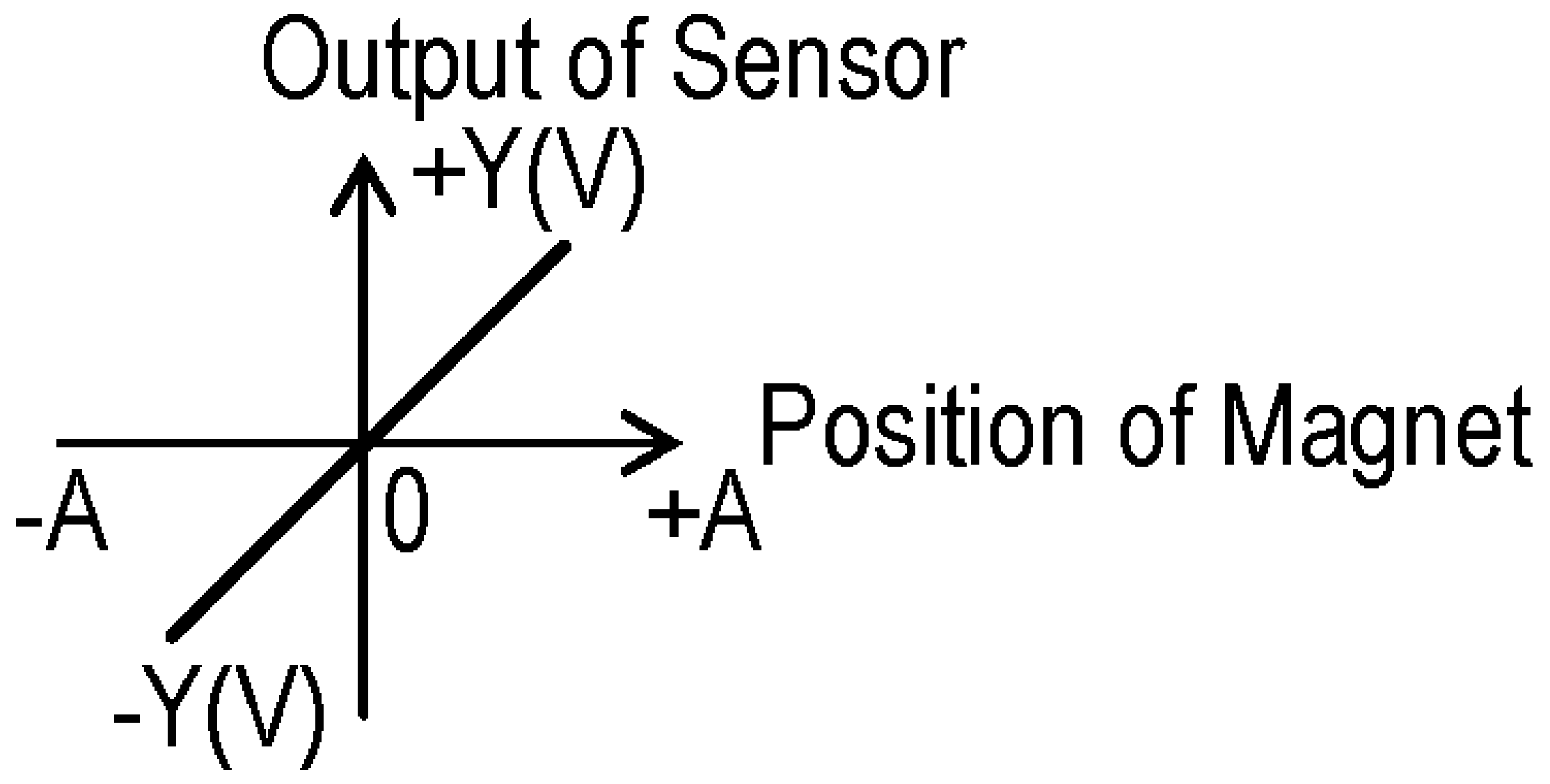


FIG. 22

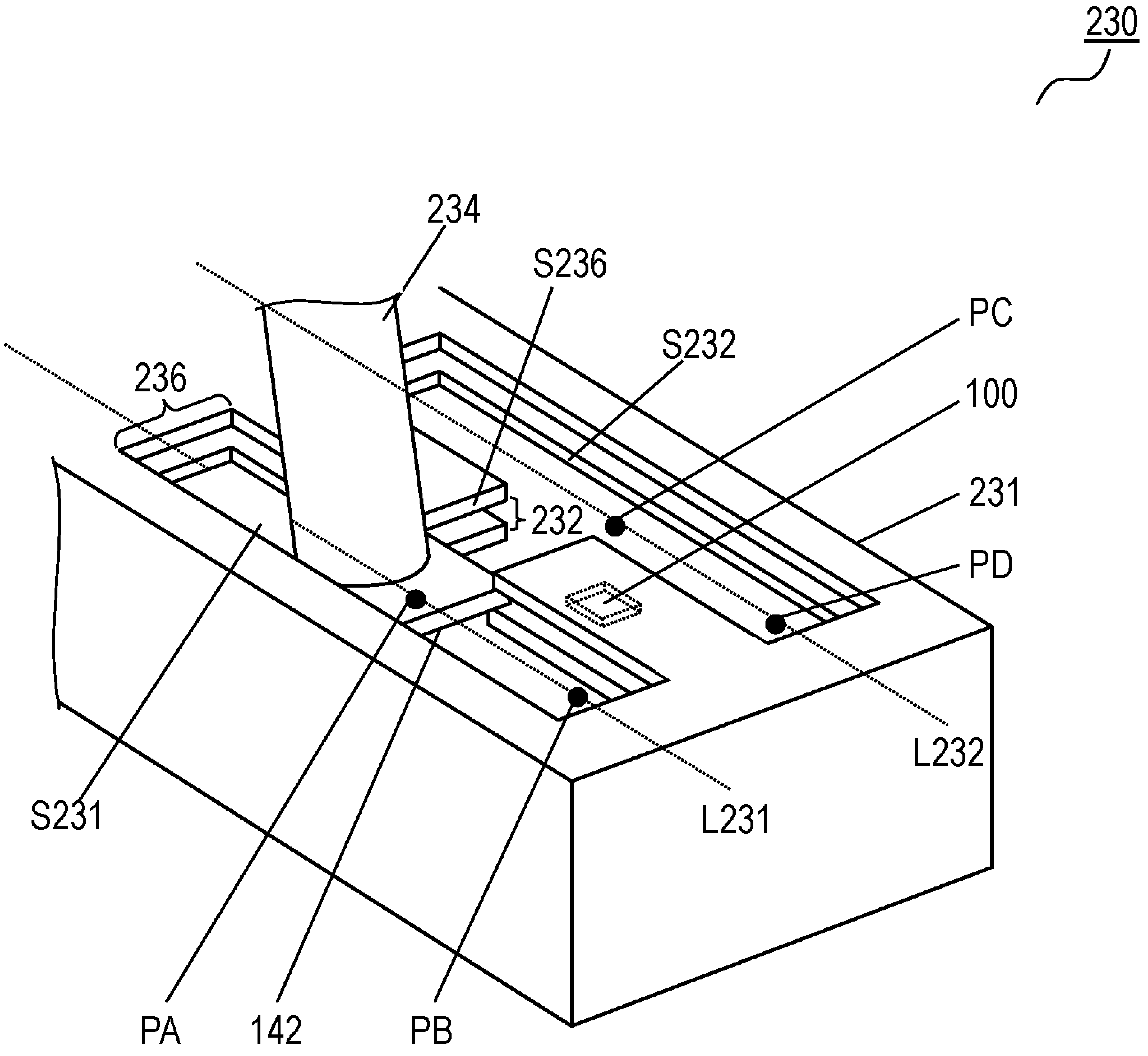


FIG. 23A

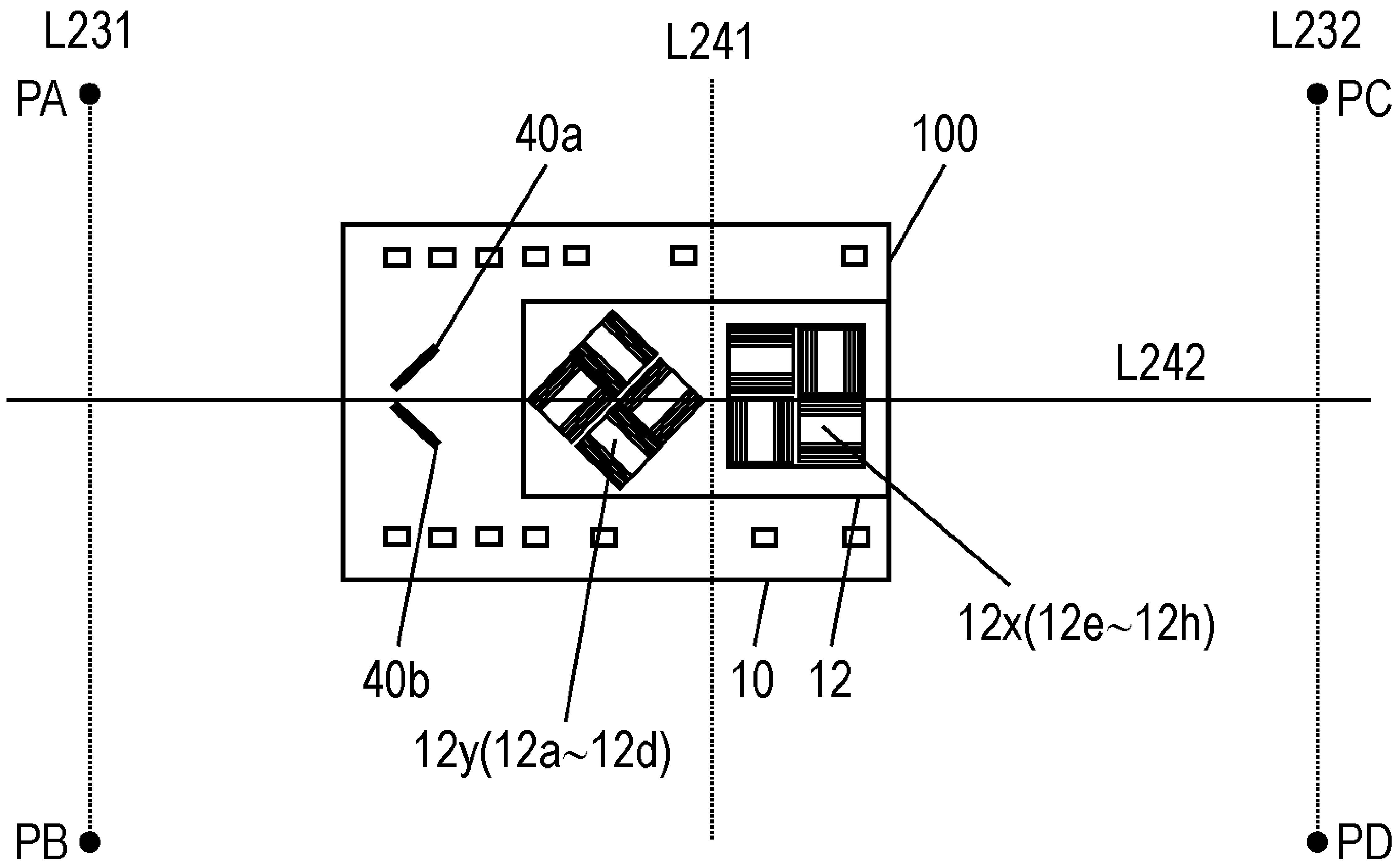


FIG. 23B

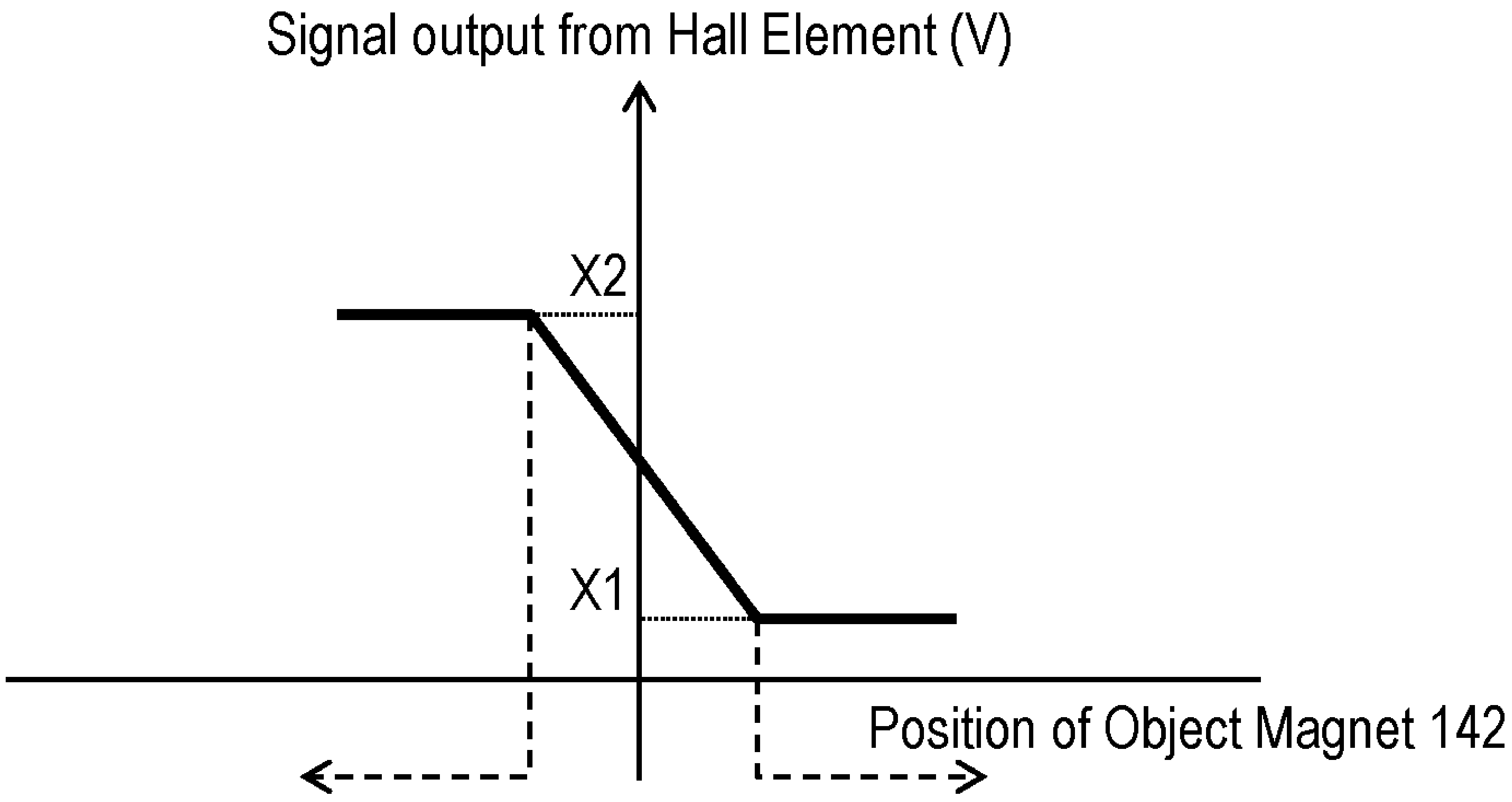


FIG. 24

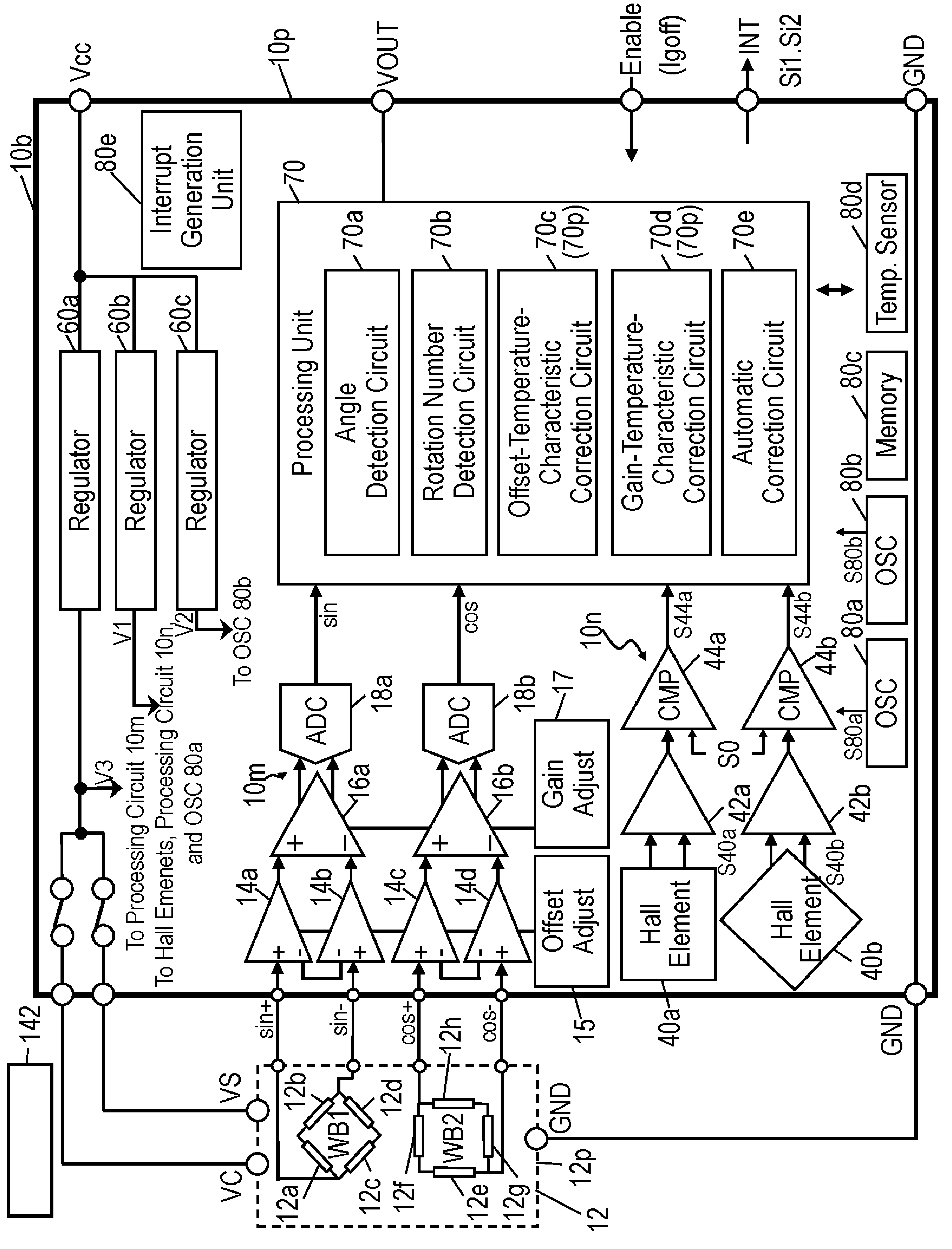

142
10b
Vcc
10p
VOUT
Enable
(Igoff)
INT
Si1.Si2
GND
80e
Interrupt Generation Unit
60a
60b
60c
Regulator
Regulator
Regulator
V1
V2
V3
To OSC 80b
To Processing Circuit 10m
To Hall Emenets, Processing Circuit 10n and OSC 80a
70
Processing Unit
70a
Angle Detection Circuit
70b
Rotation Number Detection Circuit
70c
(70p)
Offset-Temperature-Characteristic Correction Circuit
70d
(70p)
Gain-Temperature-Characteristic Correction Circuit
70e
Automatic Correction Circuit
80d
Temp. Sensor
80c
Memory
80b
OSC
S80b
80a
OSC
S80a
sin
cos
S44a
S44b
10n
44a
44b
CMP
CMP
S0
42a
42b
S40a
S40b
Hall Element
Hall Element
40a
40b
ADC
ADC
18a
18b
17
Gain Adjust
10m
16a
16b
14a
14b
14c
14d
Offset Adjust
15
sin+
sin-
cos+
cos-
GND
VS
VC
GND
12a
12b
12c
12d
12e
12f
12g
12h
12p
12
WB1
WB2

FIG. 25

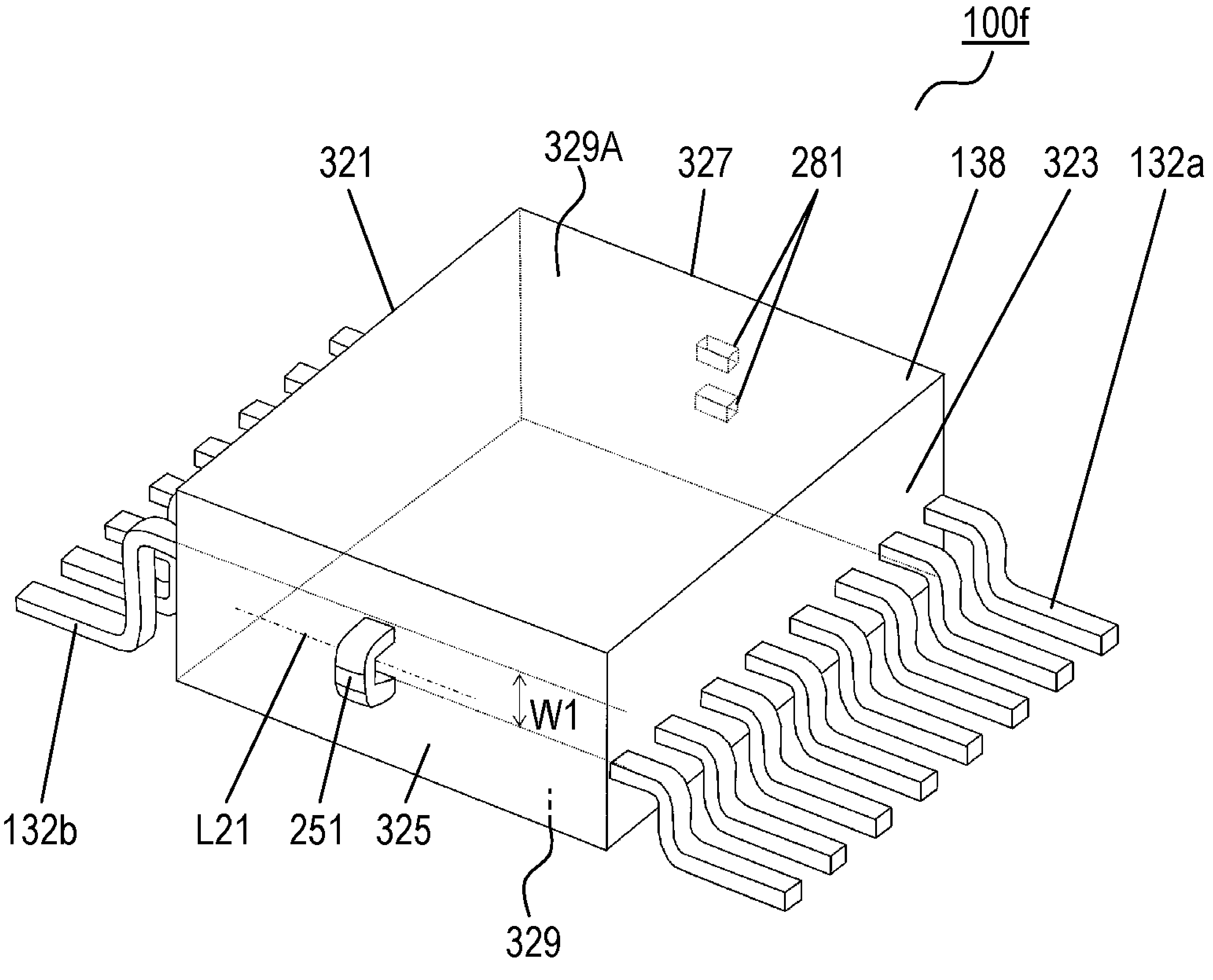


FIG. 26

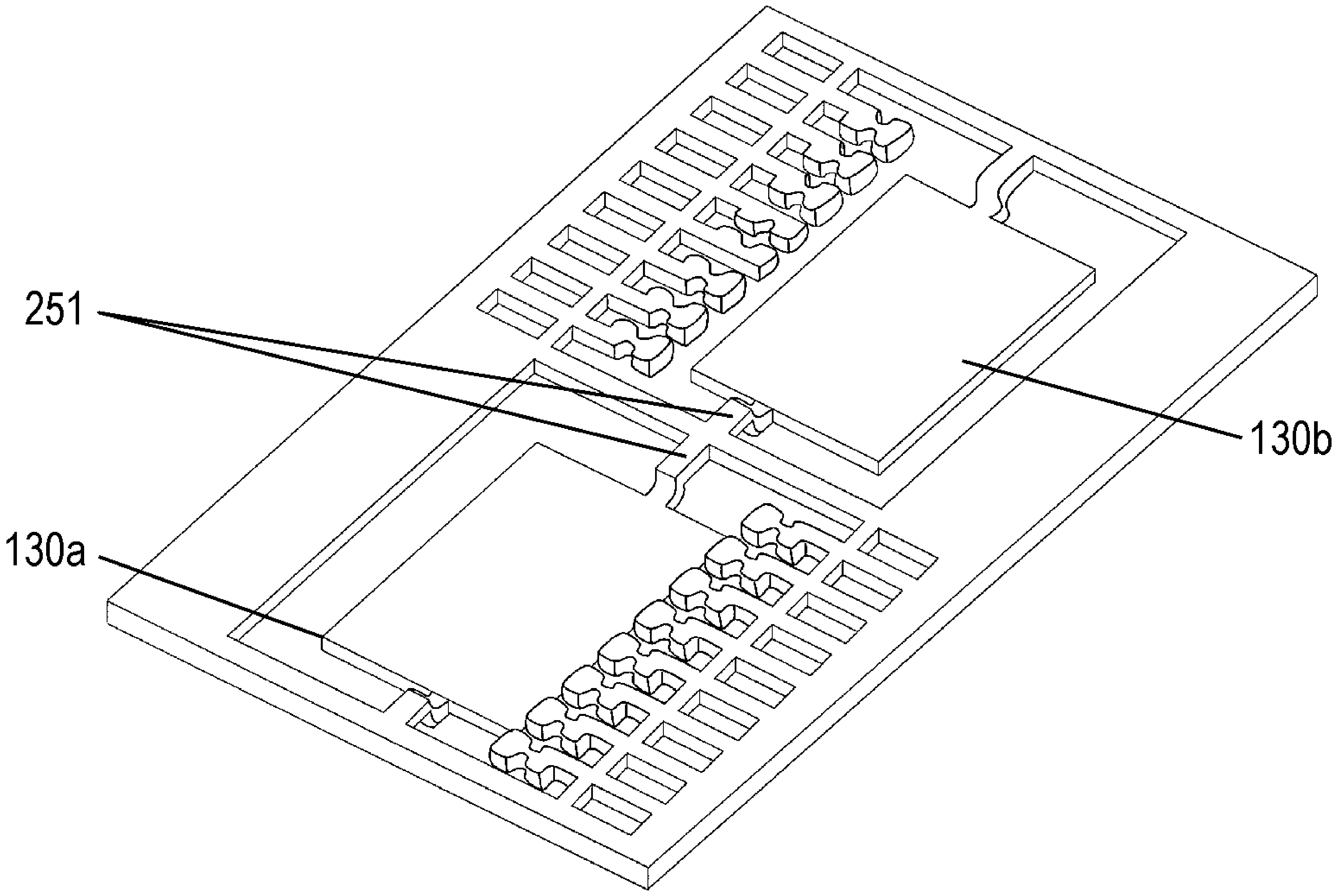


FIG. 27

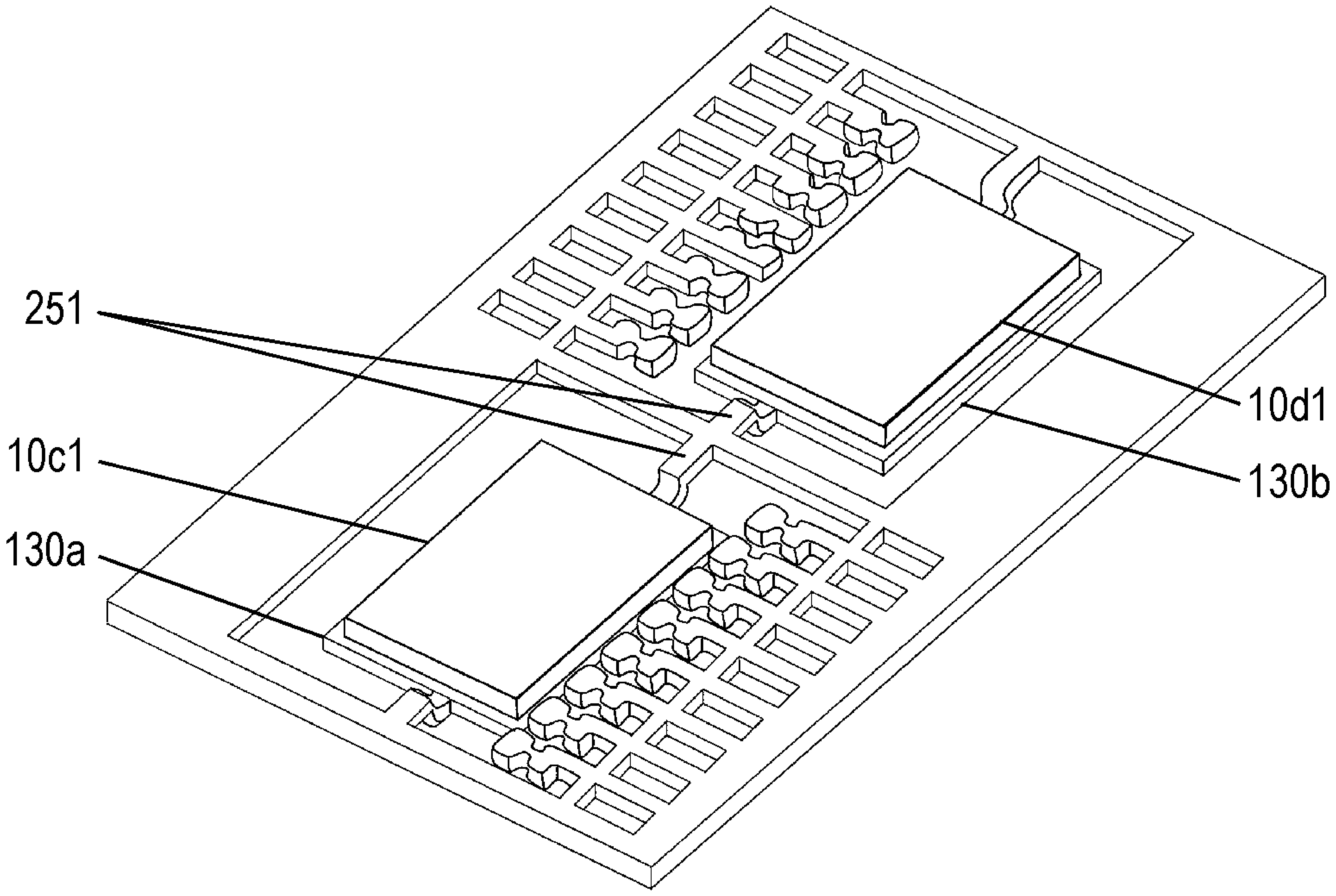


FIG. 28

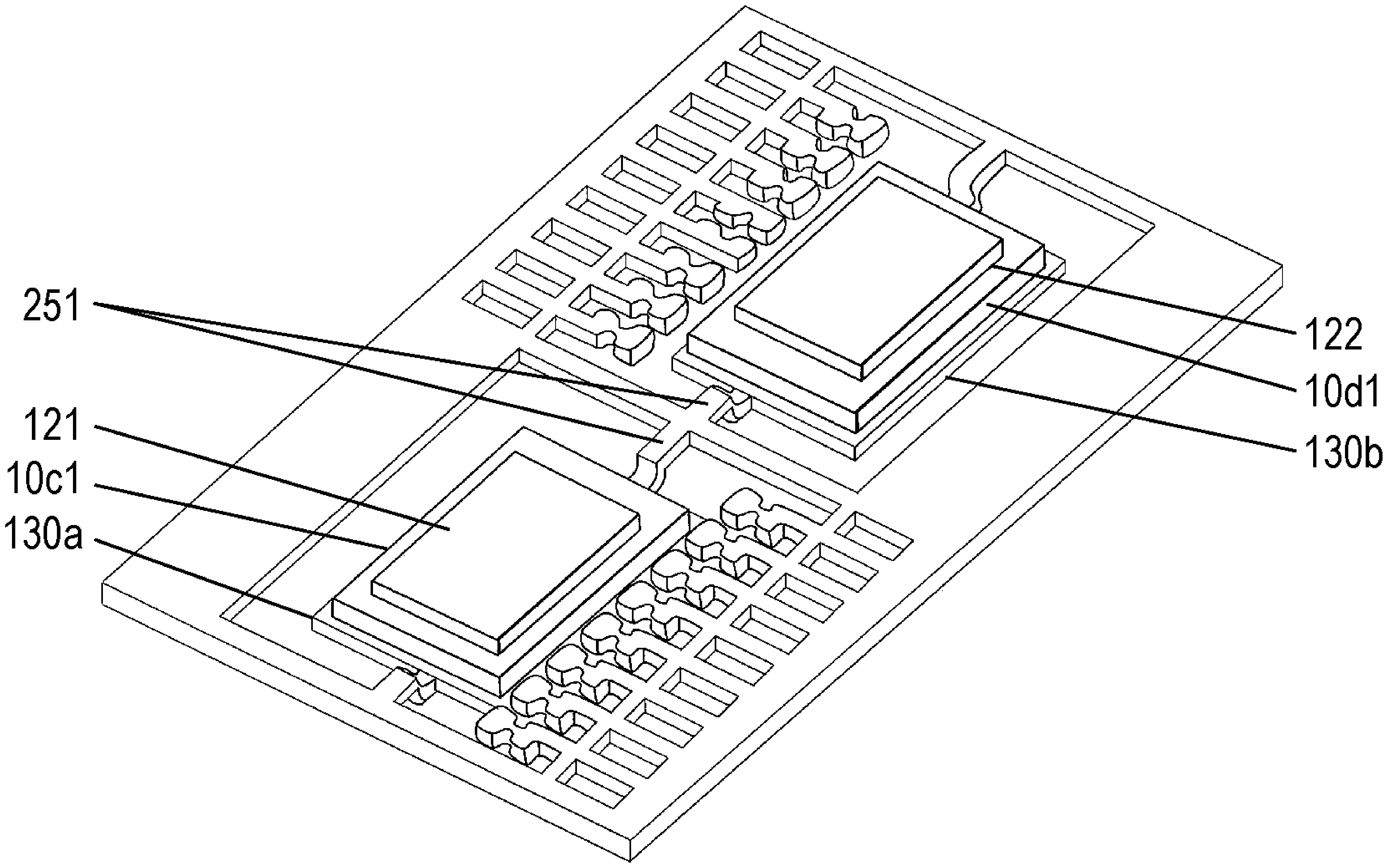

251
121
10c1
130a
122
10d1
130b

FIG. 29

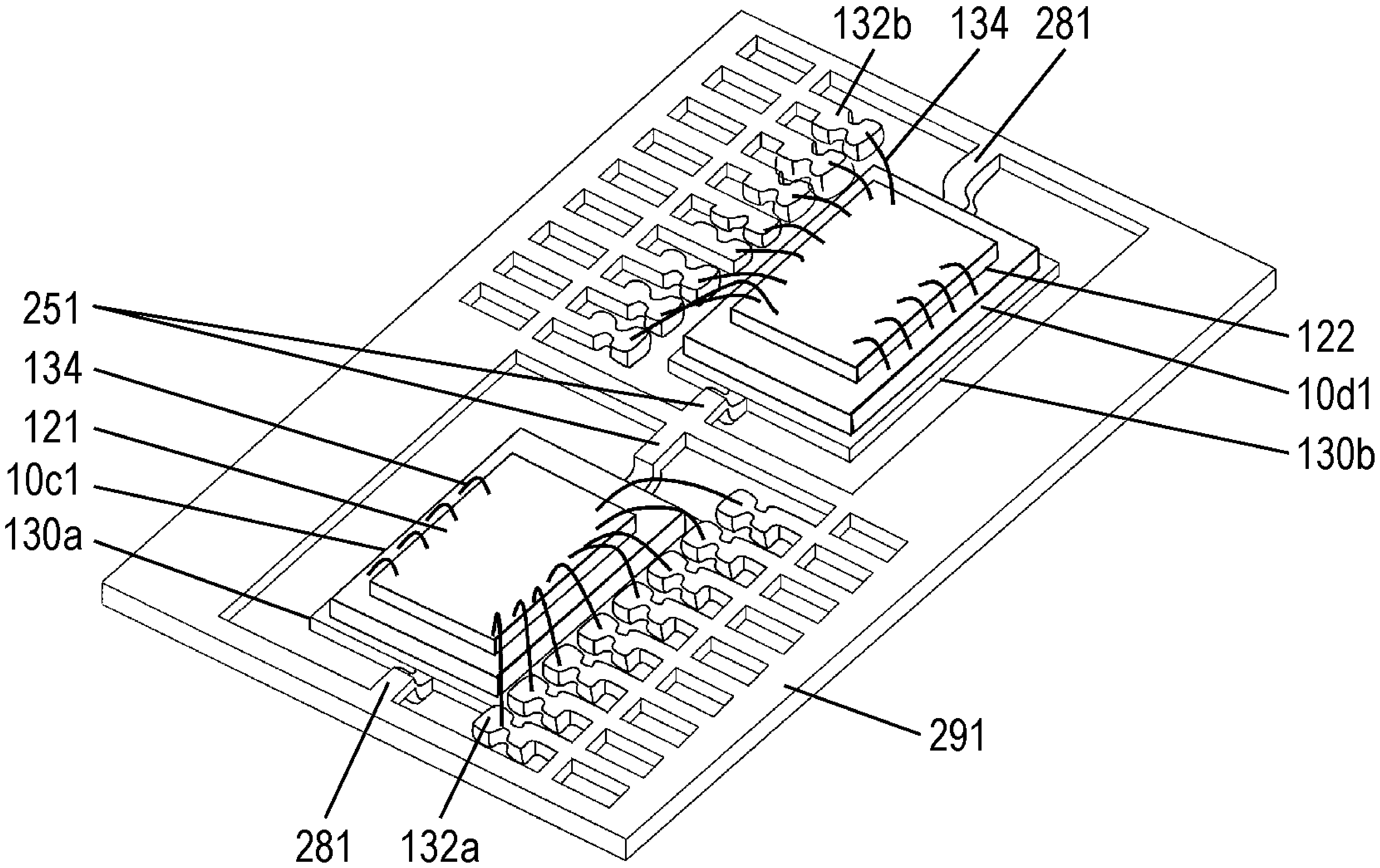

132b
134
281
251
134
121
10c1
130a
122
10d1
130b
291
281
132a

FIG. 30

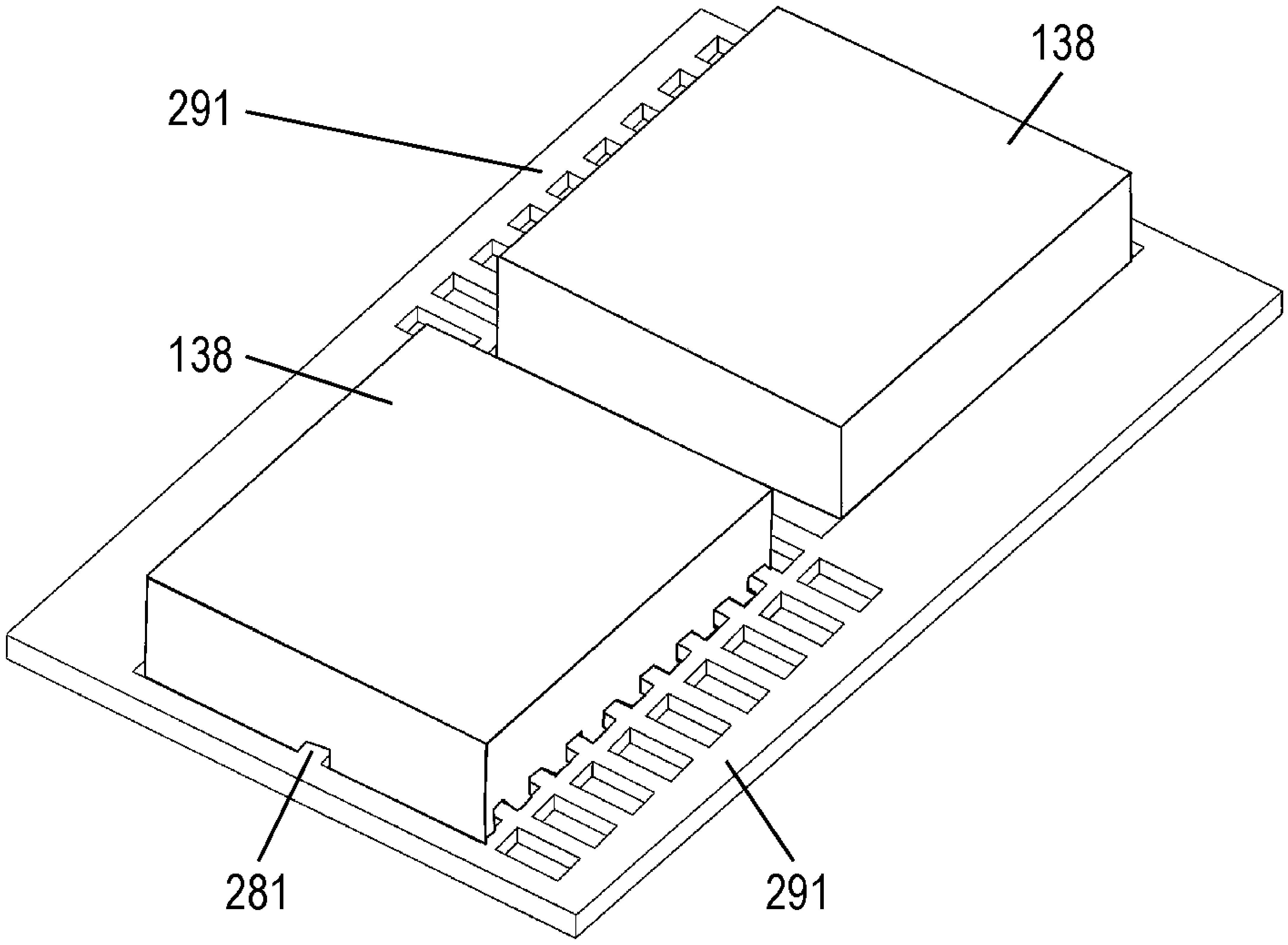


FIG. 31

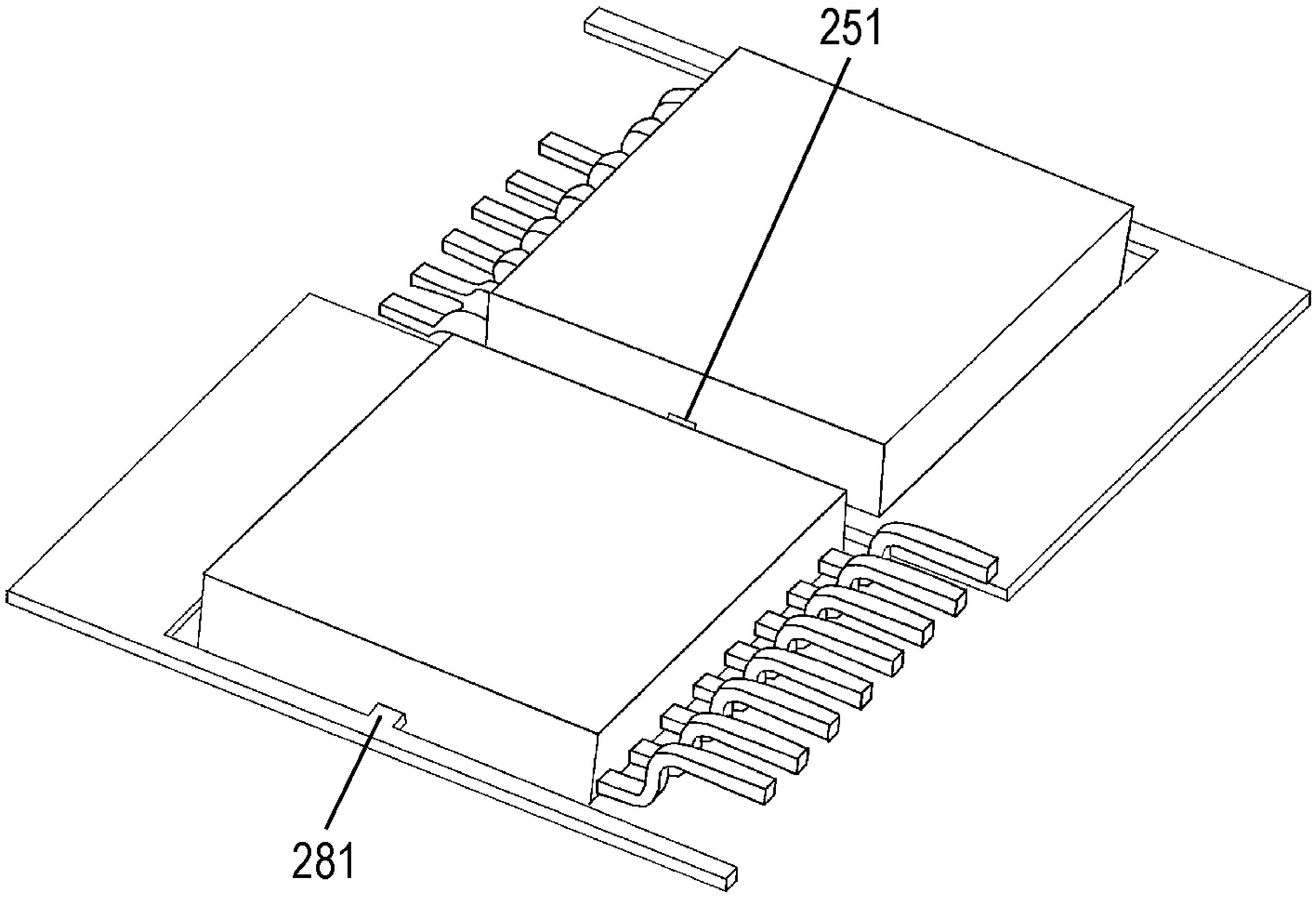


FIG. 32

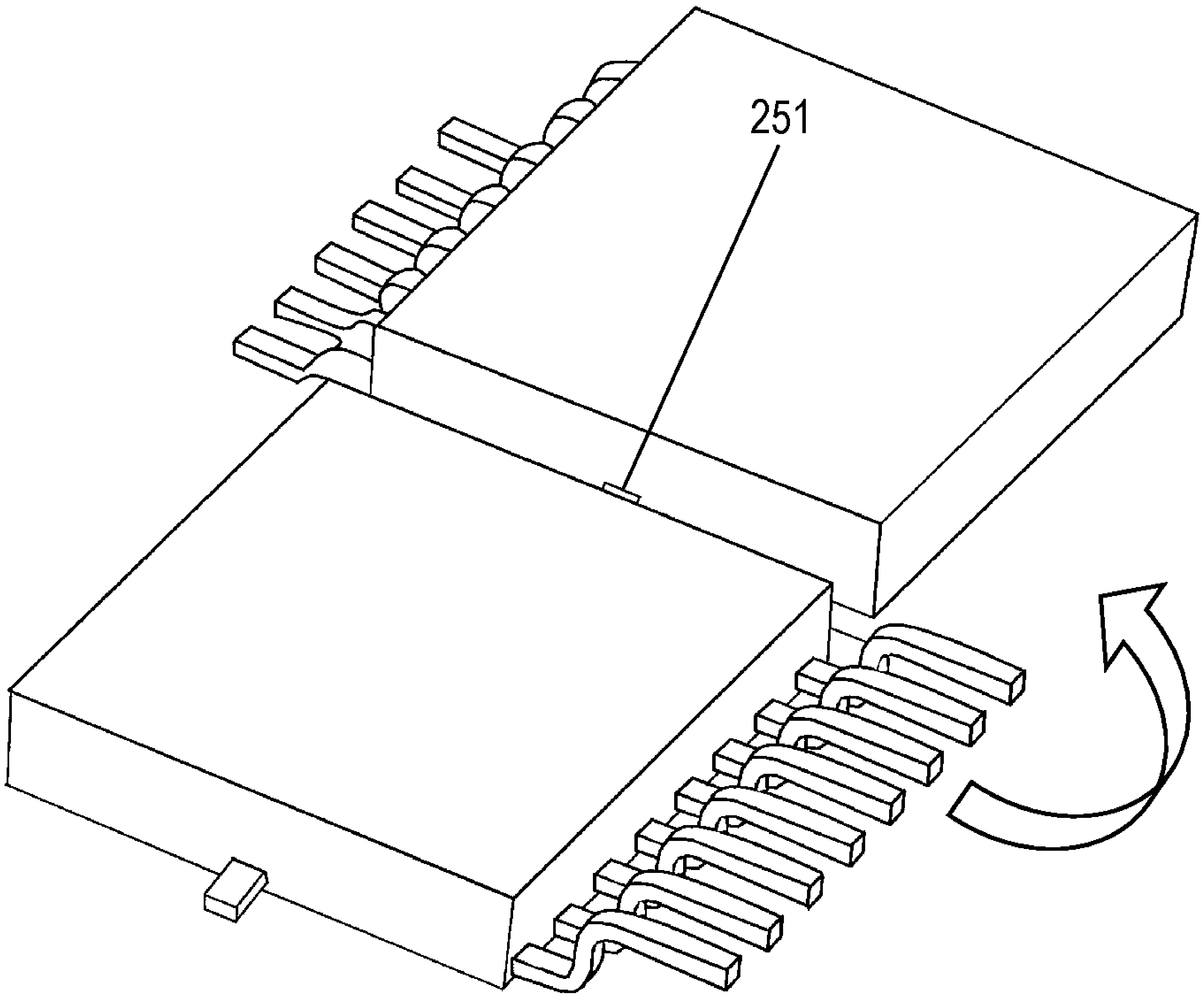


FIG. 33

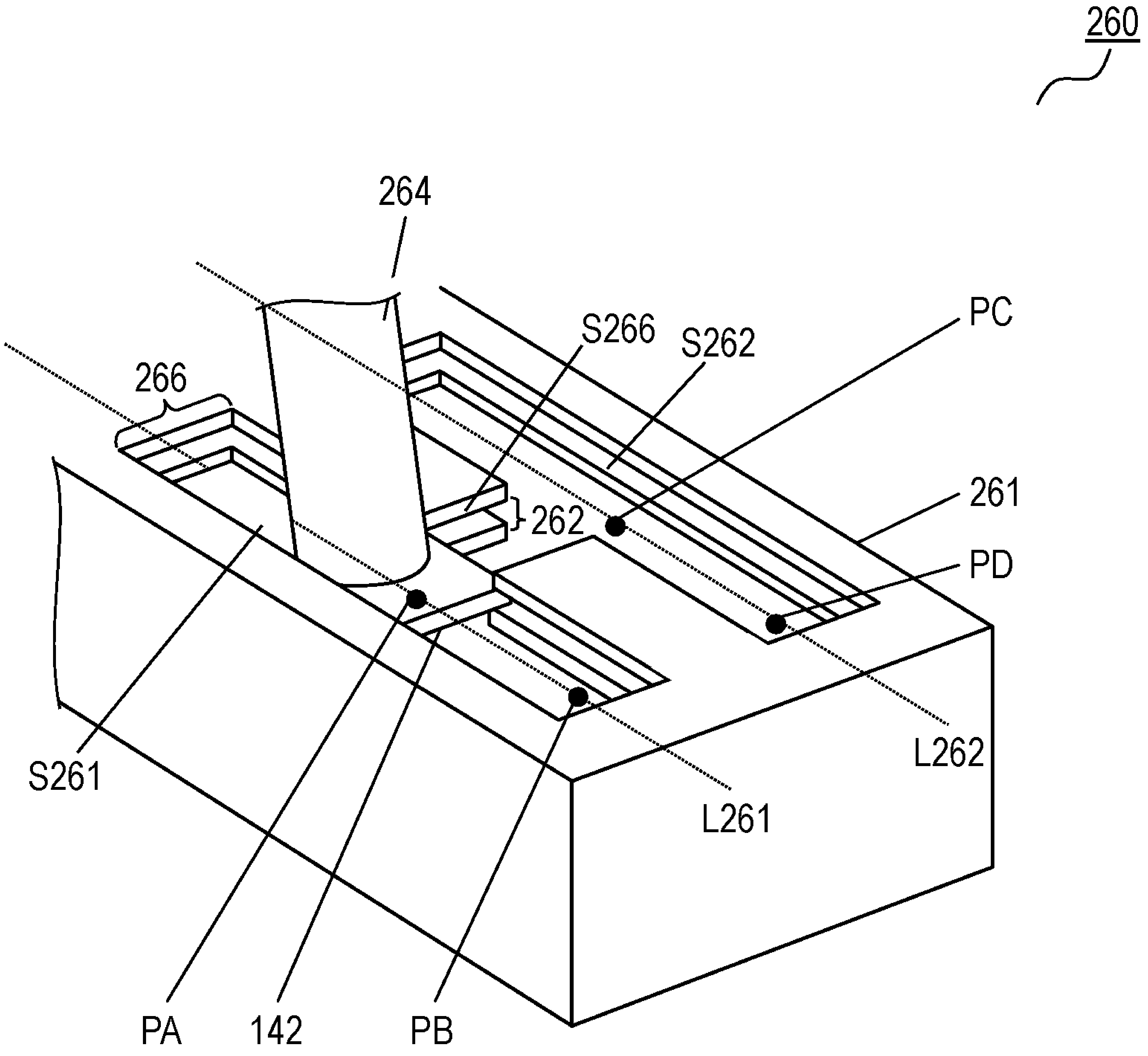


FIG. 34A

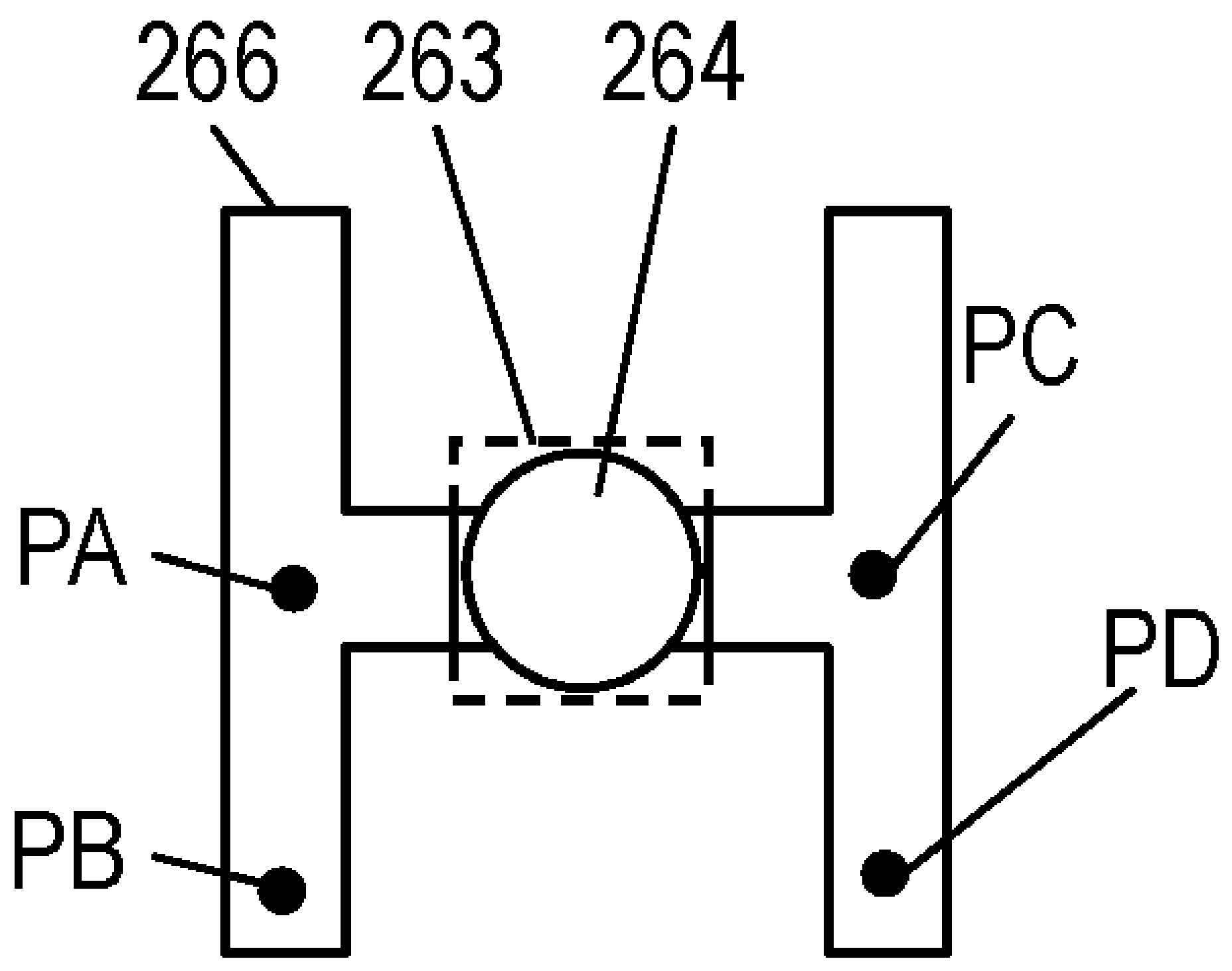


FIG. 34B

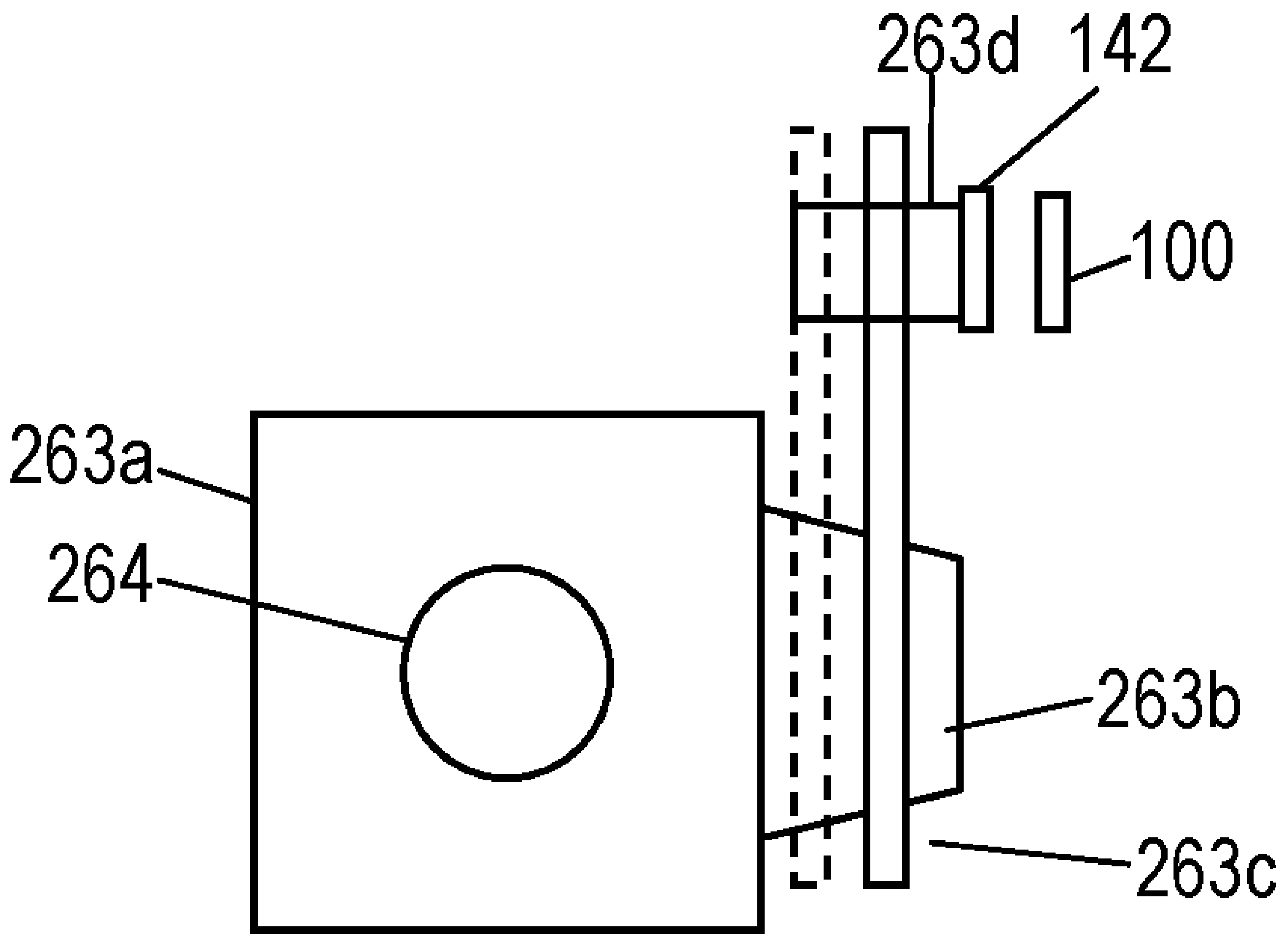
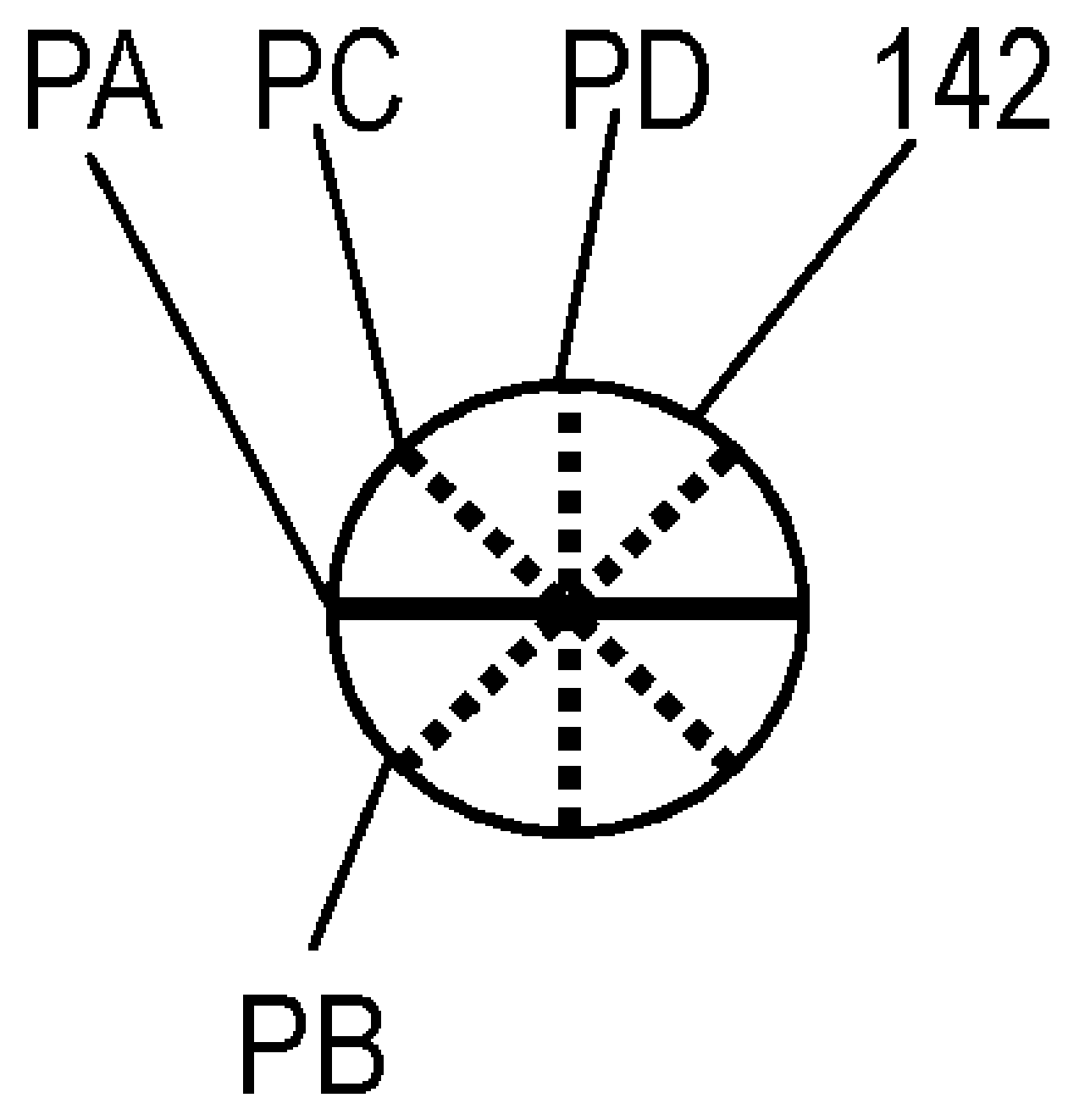


FIG. 34C



MAGNETIC SENSOR AND DETECTION DEVICE USING SAME

This application is a U.S. national stage application of the PCT international application No. PCT/JP2017/023466 filed on Jun. 27, 2017, which claims the benefit of foreign priority of Japanese patent applications No. 2016-137291 filed on Jul. 12, 2016, No. 2016-137292 filed on Jul. 12, 2016, No. 2016-151648 filed on Aug. 2, 2016, and No. 2017-005561 filed on Jan. 17, 2017, the contents all of which are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to a magnetic sensor used for detecting, e.g. a steering angle of an automobile, and to a detection device.

BACKGROUND ART

A magnetic sensor for detecting a steering angle even while an ignition switch of an automobile is turned off is known. PTLs 1 to 3 are known as prior art documents related to such a magnetic sensor.

A magnetic sensor for detecting rotation of an object which includes a steering angle or the like using a magneto-resistive element is known.

PTLs 4 to 6 are known as prior art documents related to such a magnetic sensor.

A magnetic sensor which has magnetic field generating means for diagnosing a sensor based on a magnetic field generated from the magnetic field generating means is known. PTLs 7 and 8 are known as prior art documents related to such a magnetic sensor.

A magnetic sensor combining a magneto-resistive element and a Hall element is known. PTLs 9 and 10 are known as prior art documents related to such a magnetic sensor.

A magnetic sensor including two detection systems to improve redundancy of the sensor is known. PTLs 11 to 13 are known as prior art documents relating to this magnetic sensor.

A magnetic sensor including a magneto-resistive film made of NiFe alloy to detect an external magnetic field is known. PTLs 14 to 17 are known as prior art documents relating to this magnetic sensor.

A magnetic sensor including two sensors stacked vertically to constitute one package is known. PTLs 18 to 22 are known as prior art documents relating to this magnetic sensor.

A position detecting device including a magnetic sensor to detect a position of a shift lever is known. PTLs 23 to 25 are known as prior art documents relating to this position detecting device.

Demands for high accuracy and reliability in the magnetic sensor have been increased. However, the above-mentioned magnetic sensors hardly satisfy these demands sufficiently.

CITATION LIST

Patent Literature

PTL 1: Japanese Patent Laid-Open Publication No. 2015-116964

PTL 2: International Publication WO 2014/148087

PTL 3: Japanese Patent Laid-Open Publication No. 2002-213944

PTL 4: Japanese Patent Laid-Open Publication No. 2014-209124

PTL 5: Japanese Patent No. 5708986

PTL 6: Japanese Patent Laid-Open Publication No. 2007-155668

PTL 7: Japanese Patent No. 5620989

PTL 8: Japanese Patent Laid-Open Publication No. 06-310776

PTL 9: Japanese Patent No. 4138952

PTL 10: Japanese Patent No. 5083281

PTL 11: Japanese Patent No. 3474096

PTL 12: Japanese Patent No. 4863953

PTL 13: Japanese Patent No. 5638900

PTL 14: Japanese Patent Publication No. 04-26227

PTL 15: Japanese Patent Laid-Open Publication No. 2004-172430

PTL 16: Japanese Patent Laid-Open Publication No. 2015-082633

PTL 17: Japanese Patent Laid-Open Publication No. 2015-108527

PTL 18: Japanese Patent No. 5961777

PTL 19: US Patent Publication No. 2015/0198678

PTL 20: U.S. Pat. No. 9,151,809

PTL 21: U.S. Pat. No. 8,841,776

PTL 22: U.S. Pat. No. 7,906,961

PTL 23: Japanese Patent Laid-Open Publication No. 2006-234495

PTL 24: Japanese Patent Laid-Open Publication No. 2007-333489

PTL 25: Japanese Patent Laid-Open Publication No. 2005-521597

SUMMARY

A magnetic sensor includes a magneto-resistive element, a Hall element, and a detection circuit that receives a signal from the magneto-resistive element and a signal from the Hall element input thereto.

The detection circuit includes an output terminal and an interrupt generation unit. The output terminal outputs, to the outside as an output signal, a signal obtained by performing, to the signal input from the magneto-resistive element, at least one processing selected from amplification, analog-to-digital conversion, offset correction, and temperature-characteristics correction. The interrupt generation unit outputs an interrupt signal when the signal input from the Hall element is larger than a predetermined threshold.

The magnetic sensor is accurate and highly reliable.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1**A is a block diagram of a magnetic sensor in accordance with an exemplary embodiment.

FIG. **1**B is a circuit diagram of a magnetic detection element of the magnetic sensor in accordance with the embodiment.

FIG. **2**A is a schematic view of a rotation detecting device including the magnetic sensor in accordance with the embodiment.

FIG. **2**B is a schematic view of a control system including the rotation detecting device in accordance with the embodiment.

FIG. **3** illustrates an operation of a detection circuit of the magnetic sensor in accordance with the embodiment.

FIG. **4** illustrates another operation of the detection circuit of the magnetic sensor in accordance with the embodiment.

FIG. **5** illustrates still another operation of the detection circuit of the magnetic sensor in accordance with the embodiment.

FIG. **6** illustrates an operation of the magnetic sensor in accordance with the embodiment.

FIG. **7**A is a flowchart for explaining a further operation of the detection circuit of the magnetic sensor in accordance with the embodiment.

FIG. **7**B schematically illustrates an operation of correcting the detection circuit of the magnetic sensor in accordance with the embodiment.

FIG. **7**C is a schematic diagram of the detection circuit of the magnetic sensor in accordance with the embodiment for explaining an operation of correcting of the detection circuit.

FIG. **8** is a block diagram of another magnetic sensor in accordance with the embodiment.

FIG. **9** is a top view of the magneto-resistive element and the detection circuit shown in FIG. **8**.

FIG. **10** is a front view of the magnetic sensor shown in FIG. **8**.

FIG. **11** is a top view of still another magnetic sensor in accordance with the embodiment.

FIG. **12** is a cross-sectional view of the magnetic sensor along line XII-XII shown in FIG. **11**.

FIG. **13** is a cross-sectional view of a further magnetic sensor in accordance with the embodiment.

FIG. **14** is a cross-sectional view of a further magnetic sensor in accordance with the embodiment.

FIG. **15** is a perspective view of the magnetic sensor shown in FIG. **13**.

FIG. **16** is a perspective view of the magnetic sensor shown in FIG. **15**.

FIG. **17**A is a front view of the magneto-resistive element shown in FIG. **8**.

FIG. **17**B is a cross-sectional view of the magneto-resistive element along line **17**B-**17**B shown in FIG. **17**A.

FIG. **18**A is a cross-sectional view of a magneto-resistive layer of a comparative example of a magneto-resistive element.

FIG. **18**B is a cross-sectional view of a magneto-resistive layer of the magneto-resistive element in accordance with the embodiment.

FIG. **19** illustrates a further magnetic sensor in accordance with the embodiment.

FIG. **20**A illustrates the magnetic sensor in accordance with the embodiment for illustrating an operation of the magnetic sensor when a magnet is located on the left-hand side of the magnetic sensor in accordance with the embodiment.

FIG. **20**B is a view describing the operation when the magnet is located on the left-hand side of the magnetic sensor in the exemplary embodiment.

FIG. **20**C is a view describing the operation when the magnet is located on the left-hand side of the magnetic sensor in the exemplary embodiment.

FIG. **21**A is a view describing an operation when a magnet is located on the right-hand side of the magnetic sensor in the exemplary embodiment.

FIG. **21**B is a view describing the operation when the magnet is located on the right-hand side of the magnetic sensor in the exemplary embodiment.

FIG. **21**C is a view describing the operation when the magnet is located on the right-hand side of the magnetic sensor in the exemplary embodiment.

FIG. **22** is a perspective view of another detection device in the exemplary embodiment.

FIG. **23**A is a top view of the detection device shown in FIG. **22**.

FIG. **23**B is a view showing an output of the detection device shown in FIG. **22**.

FIG. **24** is a block diagram of a magnetic sensor of the detection device shown in FIG. **22**.

FIG. **25** is a perspective view of still another magnetic sensor in the exemplary embodiment.

FIG. **26** is a view describing a manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **27** is a view describing the manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **28** is a view describing the manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **29** is a view describing the manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **30** is a view describing the manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **31** is a view describing the manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **32** is a view describing the manufacturing method of the magnetic sensor shown in FIG. **25**.

FIG. **33** is a perspective view of still another detection device in the exemplary embodiment.

FIG. **34**A is a partial top view of the detection device shown in FIG. **33**.

FIG. **34**B is a partial top view of the detection device shown in FIG. **33**.

FIG. **34**C is a front view of an object magnet of the detection device shown in FIG. **33**.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. **1**A is a block diagram of magnetic sensor **100** in accordance with an exemplary embodiment. Magnetic sensor **100** includes magneto-resistive (MR) element **12** and detection circuit **10** that is electrically connected to magneto-resistive element **12**.

FIG. **1**B is a circuit diagram of magneto-resistive element **12**. Magneto-resistive element **12** includes eight magneto-resistive elements **12***a* to **12***h*. Each magneto-resistive element is a magneto-resistive effect element that is provided on substrate **12***p*, such as a silicon substrate, and contains iron-nickel alloy. Each magneto-resistive element has an electrical resistance that changes according to a change in direction and magnitude of a magnetic field applied to the magneto-resistive element from the outside. In other words, magneto-resistive element **12** (**12***a* to **12***h*) is a magnetic detection element for detecting magnetism.

Magneto-resistive elements **12***a* to **12***d* constitute bridge circuit WB**1**. In other words, a series circuit assembly constituted by magneto-resistive elements **12***a* and **12***b* connected in series with each other is connected in parallel with a series circuit assembly constituted by magneto-resistive elements **12***c* and **12***d* connected in series with each other to form bridge circuit WB**1**. One end of bridge circuit WB**1** is connected to potential VS, and the other end of bridge circuit WB**1** is grounded through ground GND.

As shown in FIG. **1**B, end **12***a*-**2** of magneto-resistive element **12***a* is connected to end **12***b*-**1** of magneto-resistive element **12***b* at node **12***ab*, and magneto-resistive elements **12***a* and **12***b* are thus connected in series with each other. End **12***c*-**2** of magneto-resistive element **12***c* is connected to end **12***d*-**1** of magneto-resistive element **12***d* at node **12***cd*, and magneto-resistive elements **12***c* and **12***d* are thus connected in series with each other. End **12***a*-**1** of magneto-resistive element **12***a* is connected to end **12***c*-**1** of magneto-resistive element **12***c* at node **12***ac*, and magneto-resistive elements **12***a* and **12***c* are thus connected in series with each other. End **12***b*-**2** of magneto-resistive element **12***b* is connected to end **12***d*-**2** of magneto-resistive element **12***d* at node **12***bd*, and magneto-resistive elements **12***b* and **12***d* are thus connected in series with each other. Node **12***ab* is connected to potential VS which is a fixed potential, and node **12***cd* is grounded through ground GND, i.e., connected to a fixed potential. Nodes **12***ac* and **12***bd* constitute midpoints of bridge circuit WB**1**.

Magneto-resistive elements **12***e* to **12***h* constitute bridge circuit WB**2**. In other words, a series circuit assembly constituted by magneto-resistive elements **12***e* and **12***f* connected in series with each other is connected in parallel with a series circuit assembly constituted by magneto-resistive elements **12***g* and **12***h* connected in series with each other to form bridge circuit WB**2**. One end of bridge circuit WB**2** is connected to potential VC serving as a reference potential, and the other end of bridge circuit WB**2** is grounded through ground GND.

As shown in FIG. **1**B, end **12***e*-**2** of magneto-resistive element **12***e* is connected to end **12***f*-**1** of magneto-resistive element **12***f* at node **12***ef*, and magneto-resistive elements **12***e* and **12***f* are connected in series with each other. End **12***g*-**2** of magneto-resistive element **12***g* is connected to end **12***h*-**1** of magneto-resistive element **12***h* at node **12***gh*, and magneto-resistive elements **12***g* and **12***h* are connected in series with each other. End **12***e*-**1** of magneto-resistive element **12***e* is connected to end **12***g*-**1** of magneto-resistive element **12***g* at node **12***eg*, and magneto-resistive elements **12***e* and **12***g* are connected in series with each other. End **12***f*-**2** of magneto-resistive element **12***f* is connected to end **12***h*-**2** of magneto-resistive element **12***h* at node **12***fh*, and magneto-resistive elements **12***f* and **12***h* are connected in series with each other. Node **12***ef* is connected to potential VC which is a fixed reference potential, and node **12***gh* is grounded through ground GND, i.e., connected to a fixed potential. Nodes **12***eg* and **12***fh* constitute midpoints of bridge circuit WB**2**.

The bridge circuit WB**1** coincides with bridge circuit WB**2** rotated by 45°. In another expression, bridge circuit WB**2** coincides with bridge circuit WB**1** rotated by 45°.

Magnetic sensor **100** is disposed near object magnet **142**. Object magnet **142** is coupled with a rotating member (e.g., a steering shaft of an automobile), which serves as a target, via, e.g. a gear. According to a change in external magnetic field (or rotating magnetic field) applied from object magnet **142**, the resistances of magneto-resistive elements **12***a* to **12***h* change. Accordingly, signal sin+ and signal sin− are output from node **12***ac* of magneto-resistive elements **12***a* and **12***c* and node **12***bd* of magneto-resistive elements **12***b* and **12***d*, respectively. Signal sin+ and signal sin− are sine wave signals having sinusoidal wave form with phases different from each other by 180°. Magneto-resistive elements **12***a* to **12***d* constitute bridge circuit WB**1**. Signal cos− and signal cos+ are output from node **12***eg* of magneto-resistive elements **12***e* and **12***g* and node **12***fh* of magneto-resistive elements **12***f* and **12***h*, respectively. Signal cos− and signal cos+ are cosine wave signals with phases different from each other by 180°. Magneto-resistive elements **12***e* to **12***h* constitute bridge circuit WB**2**. Signal cos+ and signal cos− have phases delayed by 90° from signal sin+ and signal sin−, respectively. Signal cos+ and signal cos− are cosine wave signals output from bridge circuit WB**2**. Signal sin+ and signal sin− are sine wave signals output from bridge circuit WB**1**. Sine wave signals are obtained from bridge circuit WB**1** while cosine wave signals are obtained from bridge circuit WB**2**. This is because bridge circuit WB**1** coincides with bridge circuit WB**2** rotated by 45°. Thus, magneto-resistive element **12** outputs detection signals (signal sin+, signal sin-, signal cos+, signal cos−) according to the rotation of object magnet **142**.

Detection circuit **10** is mounted on substrate **10***p*, and performs various kinds of signal processing, such as amplification and analog-to-digital (AD) conversion of signal sin+, signal sin−, signal cos+, and signal cos−, while receiving signal sin+, signal sin−, signal cos+, and signal cos−.

A structure and operation of detection circuit **10** will be detailed below.

Amplifier **14***a* amplifies signal sin+. Amplifier **14***b* amplifies signal sin−. Amplifier **14***c* amplifies signal cos+. Amplifier **14***d* amplifies signal cos−.

Offset control circuit **15** is connected to input stages of amplifiers **14***a* to **14***d*, and controls amplifiers **14***a* to **14***d* such that a difference between midpoint potentials which are respective average values of signal sin+ and signal sin− is adjusted to be zero, and a difference between midpoint potentials which are respective average values of signal cos+ and signal cos− is adjusted to be zero.

Differential amplifier **16***a* amplifies a difference between signal sin+ and signal sin− which are output from bridge circuit WB**1** so as to generate signal sin having twice each of respective amplitudes of signal sin+ and signal sin−.

Differential amplifier **16***b* amplifies a difference between signal cos+ and signal cos− which are output from bridge circuit WB**2** so as to generate signal cos having twice each of respective amplitudes of signal cos+ and signal cos−. Signal cos is a sine wave signal with phase different from the phase of signal sin by 90°.

Gain control circuit **17** adjusts gains of differential amplifiers **16***a* and **16***b* such that signal sin and signal cos which are output from differential amplifiers **16***a* and **16***b* have predetermined amplitudes.

This configuration does not require the adjusting of offset and gain of each of amplifiers **14***a* to **14***d*, so that the signals are adjustable by one offset adjustment and one gain adjustment. This contributes particularly to reduce circuit size.

An analog signal output from differential amplifier **16***a* is sampled by AD converter **18***a* at a predetermined sampling period and converted into signal sin which is a digital signal.

An analog signal output from differential amplifier **16***b* is sampled by AD converter **18***b* at a predetermined sampling period and converted into signal cos which is a digital signal. Amplifiers **14***a* to **14***d*, differential amplifiers **16***a* and **16***b*, and AD converters **18***a* and **18***b* constitute processing circuit **10***m* that processes the signals output from magneto-resistive element **12** (**12***a* to **12***h*) and outputs signal sin and signal cos which are digital signals.

Hall element **40***a* has a detection sensitivity to a magnetic field perpendicular or parallel to the circuit substrate on which detection circuit **10** is provided, and outputs a detection signal according to a direction and magnitude of an external magnetic field (rotating magnetic field) mentioned above.

Hall element **40***b* has a detection sensitivity to a magnetic field perpendicular or parallel to the circuit substrate on which detection circuit **10** is provided, and outputs a detection signal according to a direction and magnitude of an external magnetic field (rotating magnetic field) mentioned above.

Amplifier **42***a* amplifies signal S**40***a* output from Hall element **40***a*.

Amplifier **42***b* amplifies signal S**40***b* output from Hall element **40***b*.

Comparator **44***a* converts a signal output from amplifier **42***a* into pulse signal S**44***a* with a rectangle wave shape by binarizing, i.e., comparing the signal with predetermined threshold S**0** to generate a binary signal. Threshold S**0** is a median value of signals output from amplifier **42***a*.

Comparator **44***b* converts a signal output from amplifier **42***b* into pulse signal S**44***b* with a rectangle wave shape by binarizing the signal, i.e., by comparing the signal with predetermined threshold S**0** to generate a binary signal. Threshold S**0** is a median value of signals output from amplifier **42***b*. Amplifiers **42***a* and **42***b*, and comparators **44***a* and **44***b* constitute processing **25** circuit **10***n* that processes signals output from Hall elements **40***a* and **40***b* and outputs pulse signal S**44***a* and S**44***b*.

Hall element **40***a* has a structure coinciding with a configuration of Hall element **40***b* rotated by 90°. In another expression, Hall element **40***b* has a structure identical to a configuration Hall element **40***a* rotated at 90°. The pulse signal output from Hall element **40** via comparator **44***a* has a phase difference of 90° with respect to the pulse signal output from Hall element **40***b* via comparator **44***b*.

Regulator **60***b* supplies potential V**1** to processing circuit **10***n*, oscillator (OSC) **80***a*, and Hall elements **40***a* and **40***b*.

Regulator **60***c* supplies potential V**2** to oscillator (OSC) **80***b*. Potential V**2** is used in Hall elements **40***a* and **40***b* in an intermittent operation mode.

Regulator **60***a* supplies potentials VS, VC, and V**3** to magneto-resistive element **12** and processing circuit **10***m*.

Processing unit **70** includes angle detection circuit **70***a*, rotation number detection circuit **70***b*, offset-temperature-characteristic correction circuit **70***c*, and gain-temperature-characteristic correction circuit **70***d*. Offset-temperature-characteristic correction circuit **70***c* and gain-temperature-characteristic correction circuit **70***d* constitute temperature-characteristic correction circuit **70***p*.

Angle detection circuit **70***a* detects a rotation angle of object magnet **142** from signal sin serving as a digital signal, signal cos serving as a digital signal, and pulse signals S**44***a* and S**44***b*, and outputs signal Vout. Specifically, an arctangent calculation is performed on signal sin and signal cos, i.e., a value of signal cos is divided by a value of signal sin to detect the rotation angle. Angle detection circuit **70***a* outputs an angle signal indicating the detected rotation angle.

Rotation number detection circuit **70***b* detects the number of rotations of object magnet **142** based on pulse signals S**44***a* and S**44***b* by the method described below, and outputs rotation-number information indicating the number of rotations detected above.

Offset-temperature-characteristic correction circuit **70***c* corrects, by, the method described later, a direct-current (DC) offset which occurs in signal sin or signal cos due to, e.g. a variation in resistance of magneto-resistive element **12**.

Gain-temperature-characteristic correction circuit **70***d* corrects, by the method described later, an offset of amplitude which occurs in signal sin or signal cos due to a change in temperature of magneto-resistive element **12**. In other words, a change in amplitude of signal sin or signal cos with respect to a temperature is previously measured to obtain a measured value. The measured value is stored in memory **80***c* of detection circuit **10**. Based on temperature information corresponding to the temperature obtained from temperature sensor **80***d*, the measured value stored in memory **80***c* is read out. The measured value read out from memory **80***c* is added to the amplitude of signal sin or signal cos. Thus, the offset of amplitude which occurs in signal sin or signal cos is corrected based on the temperature.

Oscillator **80***a* generates internal clock S**80***a* to be used in detection circuit **10**. Internal clock S**80***a* generated by oscillator **80***a* is used for detection in magneto-resistive element **12** and Hall elements **40***a* and **40***b*.

Oscillator **80***b* generates internal clock S**80***b* to be used in detection circuit **10**.

The frequency of internal clock S**80***b* generated in oscillator **80***b* is lower than the frequency of internal clock S**80***a* generated in oscillator **80***a*.

Memory **80***c* stores rotation-number information indicating the number of rotations measured by rotation number detection circuit **70***b*, and stores the measured value used for correcting the offset due to a change in temperature.

FIG. **2**A is a schematic view of rotation detecting device **150** including magnetic sensor **100**. Rotation detecting device **150** includes magnetic sensor **100**, object magnet **142**, rotation shaft **144** to which object magnet **142** is attached, bearing **146** for supporting rotation shaft **144**, and motor **158** for rotating rotation shaft **144**. Object magnet **142** is made of magnetic material.

FIG. **2**B is a schematic view of control system **500** including rotation detecting device **150**. Control system **500** is mounted on automobile **500***a*. Control system **500** includes steering wheel **152**, steering shaft **154**, torque sensor **156**, motor **158**, magnetic sensor **100**, and electrical control unit (ECU) **160**. ECU **160** is connected to switch **160***a*. Switch **160***a* is an ignition switch. When automobile **500***a* moves, the ignition switch is turned on. When automobile **500***a* does not move, the ignition switch is turned off. When a driver rotates steering wheel **152** to change a driving direction of automobile **500***a*, steering shaft **154** coupled to steering wheel **152** rotates in the same direction as the direction in which steering wheel **152** rotates. Torque sensor **156** detects a relative rotational displacement between an input shaft and an output shaft which is caused by the rotation of steering wheel **152**, and transmits an electric signal according to the rotational displacement to ECU **160**. Motor **158** assisting steering wheel **152** and steering shaft **154** helps a driver to change a direction of automobile **500***a* with a light force. Magnetic sensor **100** attached to motor **158** detects a rotation angle of motor **158**, thereby controlling motor **158**.

As mentioned above, magnetic sensor **100** of rotation detecting device **150** includes: bridge circuit WB**1** including magneto-resistive elements **12***a* to **12***d*, amplifier **14***a* connected to a midpoint (node **12***ac*) of bridge circuit WB**1**, amplifier **14***b* connected to a midpoint (node **12***bd*) of bridge circuit WB**1**, differential amplifier **16***a* connected to amplifiers **14***a* and **14***b*, offset control circuit **15** connected to amplifiers **14***a* and **14***b*, and gain control circuit **17** connected to differential amplifier **16***a*.

Analog-to-digital converter **18***a* may be connected to amplifiers **14***a* and **14***b*.

Magnetic sensor **100** of rotation detecting device **150** includes bridge circuit WB**1** including magneto-resistive elements **12***a* to **12***d*, bridge circuit WB**2** including magneto-resistive elements **12***e* to **12***h*, amplifier **14***a* connected to a midpoint (node **12***ac*) of bridge circuit WB**1**, amplifier **14***b* connected to a midpoint (node **12***bd*) of bridge circuit WB**1**, amplifier **14***d* connected to a midpoint (node **12***eg*) of bridge circuit WB**2**, amplifier **14***c* connected to a midpoint (node **12***fh*) of bridge circuit WB**2**, differential amplifier **16***a* connected to amplifiers **14***a* and **14***b*, differential amplifier **16***b* connected to amplifiers **14***d* and **14***c*, offset control circuit **15** connected to amplifiers **14***a* to **14***d*, and gain control circuit **17** connected to differential amplifiers **16***a* and **16***b*.

Analog-to-digital (AD) converter **18***a* may be connected to amplifiers **14***a* and **14***b* via differential amplifier **16***a*. AD converter **18***b* may be connected to amplifier **14***c* and amplifier **14***d* via differential amplifier **16***b*.

In rotation detecting device **150** including bridge circuit WB**1** including magneto-resistive element **12**, offset of an output of bridge circuit WB**1** is corrected. By amplifying the above-mentioned output with the corrected offset, the amplitude thereof is corrected.

In the correction mentioned above, the output with the corrected amplitude may be converted into a digital signal.

FIG. **3** is a flowchart showing an operation of magnetic sensor **100** in accordance with the embodiment. FIG. **3** shows an operation of magnetic sensor **100** detecting motion of a steering while switch **160***a* serving as an ignition switch is turned on.

First, after magnetic sensor **100** is activated (S**300**), if switch **160***a* is turned on ("YES" in S**301**), magnetic sensor **100** detects a rotation angle.

When switch **160***a* is turned on ("YES" in S**301**), magnetic sensor **100** detects the rotation angle based on a signal output from magneto-resistive element **12** (S**302**). In magnetic sensor **100**, one rotation of 360° is divided into four quadrants at equal angular intervals of 90° to determine the rotation angle. Based on the signals output from Hall elements **40***a* and **40***b*, magnetic sensor **100** determines one quadrant out of the four quadrants which includes a rotation angle detected in Step S**302**, and detects the number of rotations based on the signals output from Hall elements **40***a* and **40***b* (S**303**). Magnetic sensor **100** transmits the rotation angle and the number of rotations obtained in the above calculation (S**302**, S**303**) to the outside.

FIG. **4** is a flowchart of another operation of magnetic sensor **100** in accordance with the embodiment, and illustrates an operation of magnetic sensor **100** detecting motion of a steering while switch **160***a* is turned off.

First, at time point tp**1** when switch **160***a* is turned off, control system **500** inputs a control command signal to magnetic sensor **100** (S**401**). When the control command signal is input, magnetic sensor **100** is shifted to the intermittent operation mode (S**402**). When magnetic sensor **100** is shifted to the intermittent operation mode in Step S**402**, processing unit **70** detects rotation-number information (absolute-angle information) indicating the number of rotations serving as the latest absolute angle before magnetic sensor **100** is shifted to the intermittent operation mode, and then stores rotation-number information (S**403**). When the absolute-angle information is stored in Step S**403**, processing unit **70** stops supplying electric power to magneto-resistive element **12** and processing circuit **10***m* so as to deactivate magneto-resistive element **12** and processing circuit **10***m* (S**404**). After that, processing unit **70** detects only the number of rotations of object magnet **142** based on the signals output from Hall elements **40***a* and **40***b* (S**405**). Processing unit **70** stores, in memory **80***c*, rotation-number information indicating the number of rotations detected in Step S**405** (S**406**). Subsequently, if switch **160***a* is turned off ("NO" in S**407**), processing unit **70** detects only the number of rotations of object magnet **142** in Steps S**405** and S**406** based on the signals output from Hall elements **40***a* and **40***b*, and then, stores the detected number of rotations of object magnet **142** in memory **80***c*. In this way, when switch **160***a* is turned off ("NO" in S**407**), processing unit **70** detects only the number of rotations of object magnet **142** based on the signals output from Hall elements **40***a* and **40***b* every predetermined time in Steps S**405** and S**406**, and then stores the number of rotations of object magnet **142** in memory **80***c*. After time point tp**1**, if switch **160***a* is turned on in Step S**407** ("YES" in S**407**), control system **500** inputs a control command signal to magnetic sensor **100** at time point tp**2** when switch **160***a* is turned on (S**408**). Magnetic sensor **100** receives the control command signal to shift to normal mode (S**409**). When magnetic sensor **100** is transferred to the normal mode in Step S**409**, processing unit **70** detects a rotation angle of object magnet **142** based on signals output from magneto-resistive element **12** (S**410**). Based on the signals output from Hall elements **40***a* and **40***b*, processing unit **70** determines one quadrant out of the quadrants which includes the detected rotation angle of object magnet **142** (S**411**). After that, processing unit **70** outputs the rotation-number information and the absolute-angle information to the outside, simultaneously. Herein, the above-mentioned rotation-number information is obtained as a detection result of the rotation angle and the quadrant of the rotation angle. The above-mentioned absolute-angle information is stored in Step S**402** and indicates the last number of rotations stored when the intermittent operation mode has been started. The term "simultaneously" does not necessarily mean that two outputs are output at the completely same time, but may include the case where two outputs are output substantially at the same time. In this way, in the intermittent operation mode, magneto-resistive element **12** or processing circuit **10***m* does not operate temporarily, thereby reducing power consumption.

In the intermittent operation mode, internal clock S**80***b* generated by oscillator **80***b* is used for various operations of detection circuit **10**. The frequency of internal clock S**80***b* is determined according to a cycle of operations in the intermittent operation mode. The operation based on internal clock S**80***b* reduces the power consumption, and is highly efficient. Two oscillators **80***a* and **80***b* can observe (diagnosis) oscillators **80***a* and **80***b* from each other.

Rotation detecting device **150** used together with switch **160***a* detects rotation of rotation shaft **144** to which object magnet **142** serving as a magnetic body is attached. Rotation detecting device **150** includes magneto-resistive element **12** that outputs signals (signal sin, signal cos) related to displacement of the magnetic body (object magnet **142**), Hall element **40***a* (**40***b*) that is disposed at a position facing the magnetic body (object magnet **142**) and outputs signals (signals S**44***a* and S**44***b*) related to displacement of the magnetic body (object magnet **142**), and detection circuit **10** to which the above-mentioned signals (signal sin, signal cos) and the above-mentioned signals (signal S**44***a*, S**44***b*) are input. Detection circuit **10** is configured to output the above-mentioned signals (signal sin, signal cos) when switch **160***a* is turned on. At time point tp**1** when switch **160***a* is turned off, detection circuit **10** is configured to detect rotation-number information corresponding to the number of rotations of rotation shaft **144** from the above-mentioned signal (signal S**44***a*, S**44***b*). Detection circuit **10** is configured to store the rotation-number information. At time point tp**2** when switch **160***a* is turned on after time point tp**1**, detection circuit **10** is configured to output the stored rotation-number information.

Detection circuit **10** may use pulse signal S**44***a* obtained by binarizing an output of Hall element **40***a* and use pulse signal S**44***b* obtained by binarizing an output of Hall element **40***b* to detect rotation-number information.

Detection circuit **10** may use the signals (signal sin, signal cos) output from magneto-resistive element **12** to detect absolute-angle information indicating an angle of the magnetic body (object magnet **142**) at time point tp**2**. In this case, detection circuit **10** is configured to output the stored rotation-number information and the stored absolute-angle information simultaneously.

Detection circuit **10** may include oscillator **80***a* generating internal clock S**80***a*, and oscillator **80***b* generating internal clock S**80***b* having a different frequency from internal clock S**80***a*.

When switch **160***a* is turned off, detection circuit **10** may be configured to stop supplying a current supplied to oscillator **80***a* and to continue to supply current to oscillator **80***b*.

Detection circuit **10** may further include regulators **60***b* and **60***c*. Regulator **60***b* supplies potential V1 to oscillator **80***a*. Regulator **60***c* supplies potential V2 to oscillator **80***b*.

Detection circuit **10** may further include regulator **60***a* supplying potential VS (VC) to magneto-resistive element **12**.

Regulator **60***b* supplies potential V1 to Hall element **40***a* (**40***b*) and oscillator **80***a*.

The frequency of internal clock S**80***b* may be lower than the frequency of internal clock S**80***a*.

Rotation detecting device **150** (magnetic sensor **100**) includes magneto-resistive element **12**, Hall element **40***a* (**40***b*), and detection circuit **10** to which a signal from magneto-resistive element **12** and a signal from Hall element **40***a* (**40***b*) are input. Detection circuit **10** includes oscillator **80***a* generating internal clock S**80***a*, regulator **60***b* supplying potential V1 to oscillator **80***a*, oscillator **80***b* generating internal clock S**80***b*, regulator **60***c* supplying potential V2 to oscillator **80***b*, and regulator **60***a* supplying potential VS (VC) to magneto-resistive element **12**.

Regulator **60***b* may supply potential V1 to Hall element **40***a* (**40***b*) and oscillator **80***a*.

Detection circuit **10** may process the signal from magneto-resistive element **12** and the signal from Hall element **40***a* (**40***b*) based on internal clock S**80***a*. Detection circuit **10** may process the signal from Hall element **40***a* (**40***b*) based on internal clock S**80***b*.

Rotation detecting device **150** includes magneto-resistive element **12**, Hall element **40***a* (**40***b*), and detection circuit **10** to which a signal from magneto-resistive element **12** and a signal from Hall element **40***a* (**40***b*) are input. Detection circuit **10** includes oscillators **80***a* and **80***b*. Oscillator **80***a* generates internal clock S**80***a*. Oscillator **80***b* generates internal clock S**80***b* having a different frequency from internal clock S**80***a*.

FIG. **5** shows an operation of magnetic sensor **100** for detecting a rotation angle of object magnet **142** by using Hall elements **40***a* and **40***b*, and particularly shows signal S**40***a* and S**40***b* output from Hall elements **40***a* and **40***b*. In FIG. **5**, the vertical axis represents values of signal S**40***a* and S**40***b*, and the horizontal axis represents a rotation angle of object magnet **142**. FIG. **5** shows quadrants including the rotation angle of object magnet **142**. Rotation angles of object magnet **142** ranging from 0° to 90° are included in the first quadrant. Rotation angles of object magnet **142** ranging from 90° to 180° are included in the second quadrant. Rotation angles of object magnet **142** ranging from 180° to 270° are included in the third quadrant. Rotation angles of object magnet **142** ranging from 270° to 360° are included in the fourth quadrant.

The signals obtained from the magneto-resistive elements have sine and cosine waves of angles which are twice rotation angle θ of the object magnet. Therefore, a magnetic sensor equipped with only one magneto-resistive element can only detect an angle ranging from 0° to 180°. In such a magnetic sensor, for example, signals at 90° and 270° cannot be distinguished from each other since these angles correspond to the same signal.

On the other hand, as shown in FIG. **5**, the signals obtained in a Hall element typically have sine and cosine waves of angles identical to rotation angle θ of an object. Accordingly, a magnetic sensor equipped with a Hall element can detect an angle ranging from 0° to 360°.

Magnetic sensor **100** according to the embodiment includes a combination of a magneto-resistive element and a Hall element. Thus, a rotation angle of object magnet **142** is detected in a range of 0° to 360°.

FIG. **6** shows an operation of detection circuit **10** in which each magneto-resistive element detects a rotation angle of object magnet **142** while switch **160***a* is turned off. FIG. **6** shows signal sin+ and signal sin− output from bridge circuit WB**1**, signal cos+ and signal cos− output from bridge circuit WB**2**, and signal sin and signal cos output from AD converters **18***a* and **18***b* which are connected to differential amplifiers **16***a* and **16***b*, respectively. In FIG. **6**, a vertical axis represents a value of each of the signals, and a horizontal axis represents a rotation angle of object magnet **142**. FIG. **6** further shows angle signal S**70***a* output from angle detection circuit **70***a*, pulse signals S**44***a* and S**44***b* output from comparators **44***a* and **44***b*, and a quadrant including rotation angle θ of object magnet **142**.

Comparators **44***a* and **44***b* generate pulse signals S**44***a* and **44***b* by binarizing signals from Hall elements **40***a* and **40***b*, i.e., by comparing signals from Hall elements **40***a* and **40***b* with threshold S**0** to convert the signals into binary signals. When values of signals S**40***a* and S**40***b* are more than or equal to threshold S**0**, pulse signals S**44***a* and **44***b* each have a value at a high level serving as an active level. When values of signals S**40***a* and S**40***b* are less than threshold S**0**, pulse signals S**44***a* and **44***b* each have a value at a low level serving as an inactive level.

Based on pulse signals S**44***a* and S**44***b* for quadrant determination, pulse signals S**44***a* and S**44***b* are configured to have one pulse for one rotation and can count four quadrants in the one rotation. Specifically, at the time of rise and fall of pulse signal S**44***a*, the number of pulse signals S**44***a* or the number of pulse signals S**44***b* is counted according to a state of pulse signal S**44***b*. A method of calculating the number of rotations of object magnet **142** will be described below.

In accordance with the embodiment, when rotation angle θ ranges from 00 to 45° or from 225° to 360°, a value of pulse signal S**44***a* is at the high level. When rotation angle θ ranges from 45° to 225°, the value of pulse signal S**44***a* is at the low level. When rotation angle θ ranges from 0° to 135° or from 315° to 360°, a value of pulse signal S**44***b* is at the high level. When rotation angle θ ranges from 135° to 315°, the value of pulse signal S**44***b* is at the low level. While object magnet **142** rotates in normal rotation direction Df, pulse signal S**44***a* falls down at a rotation angle θ of 45°, and pulse signal S**44***a* rises up at a rotation angle θ of 225°. Similarly, while object magnet **142** rotates in normal rotation direction Df, pulse signal S**44***b* falls down at a rotation angle θ of 135°, and pulse signal S**44***b* rises up at a rotation angle θ of 315°. On the other hand, while object magnet **142** rotates in reverse rotation direction Dr, pulse signal S**44***a* rises up at a rotation angle θ of 45°, and pulse signal S**44***a* falls down at a rotation angle θ of 225°. Similarly, while object magnet **142** rotates in reverse rotation direction Dr, pulse signal S**44***b* rises up at a rotation angle θ of 135°, and pulse signal S**44***b* falls down at a rotation angle θ of 315°. Accordingly, when rotation angle θ becomes 45° or 225° at which the value of pulse signal S44*a* is changed, rotation number detection circuit **70***b* determines the rotation direction.

Object magnet **142** rotates in two directions i.e., normal rotation direction Df and reverse rotation direction Dr opposite to normal rotation direction Df. When the value of pulse signal S44*a* changes, rotation number detection circuit **70***b* of processing unit **70** detects the rotation direction and the number of rotations of object magnet **142** based on the value of pulse signal S44*b* and the change of the value of pulse signal S44*a*.

Specifically, in accordance with the embodiment, rotation number detection circuit **70***b* will determine that object magnet **142** rotates in normal rotation direction Df by one rotation if detecting that the value of pulse signal S44*b* is at the low level at the time when the value of pulse signal S44*a* rises to change from the low level to the high level, and subsequently, the value of pulse signal S44*b* is at the high level at the time when the value of pulse signal S44*a* falls to change from the high level to the low level, and subsequently, the value of pulse signal S44*b* is at the low level at the time when pulse signal S44*a* rises.

Rotation number detection circuit **70***b* determines that object magnet **142** rotates in reverse rotation direction Dr by one rotation if detecting that: the value of pulse signal S44*b* is at the high level at the time when pulse signal S44*a* rises, and subsequently, the value of pulse signal S44*b* is at the low level at the time when pulse signal S44*a* falls down, and subsequently, the value of pulse signal S44*b* is at the high level at the time when pulse signal S44*a* rises.

The rotation angle between object magnet **142** and motor **158** rotating while switch **160***a* is turned off can thus be detected precisely with low electric power at the time when switch **160***a* is turned on again.

Processing unit **70** of magnetic sensor **100** has an active correction mode and a passive correction mode. The active correction mode is an auto-calibration mode for correcting signal sin and signal cos output from magneto-resistive element **12** via processing circuit **10***m*. The passive correction mode is a temperature-characteristic correction mode.

First, an operation of the passive correction mode will be described.

Memory **80***c* stores formulas indicating a relation between temperature and offset included in each of signal sin and signal cos output from magneto-resistive element **12** via processing circuit **10***m*. In accordance with the embodiment, memory **80***c* stores coefficients of polynomial function that approximate the relation between the temperature and the offset included in each of signal sin and signal cos. Memory **80***c* further stores formulas indicating a relation between temperature and amplitude of each of signal sin and signal cos converted into digital signals. In accordance with the embodiment, memory **80***c* stores coefficients of polynomial function that approximate the relation between the temperatures and the amplitude of each of signal sin and signal cos converted into digital signals.

Temperature sensor **80***d* outputs temperature information which is a digital signal corresponding to temperature. Offset-temperature characteristic correction circuit **70***c* performs arithmetic processing based on temperature information input from temperature sensor **80***d* and the coefficients of relation function between the offset and the temperature stored in memory **80***c*. Thus, a change in the offset of each of signal sin and signal cos which depends on temperature is corrected.

Gain-temperature-characteristic correction circuit **70***d* performs arithmetic processing based on temperature information input from temperature sensor **80***d* and the coefficients of relation function between amplitude and temperature stored in memory **80***c*. Thus, a change in amplitude of each of signal sin and signal cos which depends on temperature is corrected.

Next, the active correction mode will be described.

In the active correction mode, automatic correction circuit **70***e* generates and updates a correction value for correcting the offset and the amplitude of each of signal sin and signal cos output from magneto-resistive element **12** via processing circuit **10***m*. Automatic correction circuit **70***e* thus updates the correction value every one rotation of object magnet **142**. Based on the updated correction value, signal sin and signal cos are corrected such that signal sin and signal cos continuously have a fixed midpoint and fixed amplitude.

FIG. 7A shows an operation of detection circuit **10** in the active correction mode.

Processing unit **70** determines whether processing unit **70** is in the active correction mode or not (S**702**). In the active correction mode ("Yes" in step S**702**), automatic correction circuit **70***e* of processing unit **70** stores maximum value Vmax**1** and minimum value of signal sin output from magneto-resistive element **12** via processing circuit **10***m*, and stores maximum value Vmax**2** and minimum value Vmin**2** of signal cos output from magneto-resistive element **12** via processing circuit **10***m* (S**703**). After that, automatic correction circuit **70***e* determines whether object magnet **142** rotates by one rotation or not (S**704**). When determining that object magnet **142** rotates by one rotation in step S**704** ("Yes" in step S**704**), automatic correction circuit **70***e* performs the calculation of (Vmax**1**+Vmin**1**)/2 to generate and update the correction value for correcting the offset of signal sin. Further, automatic correction circuit **70***e* performs the calculation of (Vmax**2**+Vmin**2**)/2 to generate and update the correction value for correcting the offset of signal cos. At the same time, automatic correction circuit **70***e* performs the calculation of (Vmax**1**−Vmin**1**) to update the correction value for correcting the amplitude of signal sin. Further, automatic correction circuit **70***e* performs the calculation of (Vmax**2**-Vmin**2**) to update the correction value for correcting the amplitude of signal cos (S**705**). After that, the stored maximum values Vmax**1** and Vmax**2** and the stored minimum values Vmin**1** and Vmin**2** are reset to zero (S**706**). Subsequently, processing unit **70** determines, in step S**702**, whether processing unit **70** is in active correction mode or not.

Based on the updated offset and amplitude, signal sin and signal cos are corrected until object magnet **142** completes the next one rotation.

When it is determined that object magnet **142** does not rotate by one rotation in step S**704** ("No" in step S**704**), processing unit **70** determines, in step S**702**, whether processing unit **70** is in the active correction mode or not.

In the active correction mode ("Yes" in step S**702**), automatic correction circuit **70***e* continues to store the maximum values Vmax**1** and Vma**2** and the minimum values Vmin**1** and Vmin**2** until object magnet **142** completes the next one rotation. Since that time, the same operation as step S**703** is repeated. Automatic correction circuit **70***e* continues to store the maximum values Vmax**1** and Vma**2** and the minimum values Vmin**1** and Vmin**2** during the one rotation until object magnet **142** completes the next one rotation.

If processing unit **70** is not in the active correction mode ("No" in step S702), processing unit **70** does not perform the process shown in FIG. 7A.

Rotation number detection circuit **70***b* determines whether object magnet **142** rotates by one rotation or not based on the pulse signals S44*a* and S44*b* by the above-mentioned method at the time when the value of rotation angle θ output from angle detection circuit **70***a* is jumped to 0° from 3600 (normal rotation direction Df) or at the time when the value of rotation angle θ is jumped to 360° from 0° (reverse rotation direction Dr). When a direction (normal rotation direction Df or reversal direction Dr) of the rotation is different from the latest determination, rotation number detection circuit **70***b* determines that object magnet **142** does not rotate by one rotation, and automatic correction circuit **70***e* does not update the correction values of the offset and amplitude of signal sin and signal cos. The operation will be detailed below.

FIG. **7**B and FIG. **7**C are schematic diagrams illustrating an operation correcting rotation angle θ detected by rotation number detection circuit **70***b* in the active correction mode. In FIG. **7**B and FIG. **7**C, the vertical axis represents a value of rotation angle θ of object magnet **142** calculated in angle detection circuit **70***a*, and a horizontal axis represents time.

In the operation shown in FIG. **7**B, object magnet **142** rotates in normal rotation direction Df over a period from before time point t**0** until after time point t**13**. According to this rotation, rotation angle θ output from rotation number detection circuit **70***b* increases at time point t**0**. Rotation angle θ reaches 360° and jumps to 0° at time point t**11**, and then, starts increasing. Rotation angle θ starts increasing from 0° at time point t**11**, and then, reaches 360° and jumps to 0° at time point t**12**, and then starts increasing again. Rotation angle θ starts increasing from 0° at time point t**12**. Rotation angle θ reaches 360° and jumps to 0° at time point t**13**, and then, starts increasing again. As mentioned above, based on pulse signals S44*a* and S44*b*, rotation number detection circuit **70***b* determines that object magnet **142** rotates by one rotation in normal rotation direction Df before each of time points t**11**, t**12**, and t**13**. When determining that object magnet **142** rotates in the same direction as the last-time determination, i.e., normal rotation direction Df, automatic correction circuit **70***e* updates correction values of offset and amplitude of each of signal sin and signal cos at time points t**12** and t**13**. At time point t**11** when the rotation direction is not determined, automatic correction circuit **70***e* does not update the correction values of the offset and amplitude each of signal sin and signal cos.

Similarly, when the rotation direction determined last time is the reverse rotation direction and the rotation direction determined at this time is the reverse rotation direction, automatic correction circuit **70***e* determines that object magnet **142** rotates by one rotation, and updates the correction values.

In the operation shown in FIG. **7**C, object magnet **142** rotates in normal rotation direction Df from before time point t**0** until time point t**21***p* through time point t**21**, and rotates in reverse rotation direction Dr from time point t**21***p* until time point t**23***p* through time points t**22** and t**23**. Then, object magnet **142** rotates in normal rotation direction Df from time point t**23***p* until after t**24**. In the operation, the rotation direction in which object magnet **142** is rotated changes at time points t**21***p* and t**23***p*. According to the rotation, rotation angle θ output from rotation number detection circuit **70***b* increases at time point t**0**. At time point t**21**, rotation angle θ reaches 360° and jumps to 0°, and then starts increasing. Rotation angle θ starts increasing from 0° at time point t**21**. At time point t**21***p*, rotation angle θ reaches 180°, and then starts decreasing. Rotation angle θ starts decreasing from 180° at time point t**21***p*. At time point t**22**, rotation angle θ reaches 0° and jumps to 360°, and then starts decreasing again. Rotation angle θ starts decreasing from 360° at time point t**22**. At time point t**23**, rotation angle θ reaches 0° and jumps to 360°, and then starts decreasing again. Rotation angle θ starts decreasing from 360° at time point t**23**. At time point t**23***p*, rotation angle θ reaches 270°, and then starts increasing from 270°. Rotation angle θ starts increasing from 270° at time point t**23***p*. At time point t**24**, rotation angle θ reaches 360° and jumps to 0°, and then starts increasing again. As mentioned above, based on pulse signals S**44***a* and S**44***b*, rotation number detection circuit **70***b* determines that object magnet **142** rotates by one rotation in reverse rotation direction Dr before each of time points t**22** and t**23**. When it is determined that object magnet **142** rotates in the same direction as the last time determination, i.e., reverse rotation direction Dr, automatic correction circuit **70***e* updates the correction values of the offset and amplitude of each of signal sin and signal cos at time point t**23**.

As shown in FIG. **7**C, the rotation direction at time point t**21** in the last time determination is normal rotation direction Df, and a rotation direction at time point t**22** in this time determination is reverse rotation direction Dr. In this case, automatic correction circuit **70***e* determines that object magnet **142** does not rotate by one rotation, and does not update the correction values.

After that, in the case where the rotation direction at time point t**22** in the last time determination is reverse rotation direction Dr and a rotation direction at time point t**23** in this time determination is reverse rotation direction Dr, automatic correction circuit **70***e* determines that object magnet **142** rotates by one rotation, and updates the correction values.

After that, in the case where the rotation direction at time point t**23** in the last time determination is reverse rotation direction Dr and a rotation direction at time point t**24** in this time determination is normal rotation direction Df, automatic correction circuit **70***e* determines that object magnet **142** does not rotate by one rotation, and does not update the correction values.

When not updating the correction values, automatic correction circuit **70***e* does not necessarily generate a correction value.

The correction values are updated in the configuration even when the offset and amplitude of each of signal sin and signal cos from magneto-resistive element **12** change with respect to time. This operation maintains the offset and amplitude constant. At the same time, even when object magnet **142** rotates in both directions, i.e., normal rotation direction Df and reverse rotation direction Dr, offset can be updated correctly.

Magnetic sensor **100** does not preferably operate in the passive correction mode when operating in the active correction mode. Magnetic sensor **100** does not preferably operate in the active correction mode when operating in the passive correction mode. In another expression, magnetic sensor **100** switches between the active correction mode and the passive correction mode to operate. In the configuration, while magnetic sensor **100** operates in the active correction mode, signal sin and signal cos are corrected with respect to all of temporal changes including temperature characteristics. Therefore, magnetic sensor **100** does not necessarily operate in the passive correction mode. On the other hand, in the active correction mode, the correction values are not updated until object magnet **142** rotates by one rotation. Accordingly, in the case where object magnet **142** does not rotate by one rotation, if the offset and the amplitude are changed largely during the rotation of object magnet **142**, magnetic sensor **100** operate more preferably in the passive correction mode than in the active correction mode.

In the active correction mode, both the offset and amplitude of the signal are corrected, but not limited to this. At least one of the offset and amplitude may be corrected, i.e., only the offset out of the offset and amplitude may be corrected, or only the gain out of the offset and amplitude may be corrected.

In description of the active correction mode and the passive correction mode, signal sin and signal cos from magneto-resistive element **12** are corrected, but not limited to this. As long as being a magnetic detection element for detecting a magnetic field from object magnet **142** and outputting signal sin and signal cos according to the rotation of object magnet **142**, magneto-resistive element **12** is not necessarily made of magneto-resistive material. In other words, the active correction mode and the passive correction mode can be used for correcting signal sin and signal cos of the magnetic detection element.

As mentioned above, rotation detecting device **150** (magnetic sensor **100**) for detecting rotation of an object (object magnet **142**) includes magnetic detection elements (magneto-resistive elements **12***a* and **12***c*) that output signal sin, magnetic detection elements (magneto-resistive elements **12***e* and **12***f*) that output signal cos, and detection circuit **10** to which signal sin and signal cos are input. Detection circuit **10** includes automatic correction circuit **70***e* that performs generation and update of correction values to correct signal sin and signal cos. Automatic correction circuit **70***e* is configured to stop the generation or the update of correction values in at least one of the case where a rotation direction of the object (object magnet **142**) changes from normal rotation direction Df to reverse rotation direction Dr, or the case where a rotation direction of the object (object magnet **142**) changes from reverse rotation direction Dr to normal rotation direction Df.

Detection circuit **10** may further include angle detection circuit **70***a* that outputs an angle signal indicating the rotation angle of the object (object magnet **142**) based on signal sin and signal cos. In this case, a rotation direction in which an angle of the angle signal changes to 0° from 360° is normal rotation direction Df. A rotation direction in which an angle of the angle signal changes to 360° from 0° is reverse rotation direction Dr.

Signal sin is a sine wave signal, and signal cos is a sine wave signal. Detection circuit **10** may further include angle detection circuit **70***a* that performs an are tangent calculation on signal sin and signal cos to obtain the angle signal. In this case, a rotation direction in which an angle of the angle signal changes to 0° from 360° is normal rotation direction Df, and a rotation direction in which the angle changes from 0° to 360° is reverse rotation direction Dr.

Detection circuit **10** may further include temperature-characteristic correction circuit **70***p* that corrects at least one of the amplitude and offset of each of signal sin and signal cos according to the temperature. In this case, detection circuit **10** has an active correction mode in which automatic correction circuit **70***e* corrects signal sin and signal cos without temperature-characteristic correction circuit **70***p*, and a passive correction mode in which temperature-characteristic correction circuit **70***p* corrects signal sin and signal cos without automatic correction circuit **70***e*. Detection circuit **10** is configured to switch between the active correction mode and the passive correction mode.

Detection circuit **10** may further include temperature sensor **80***d* that detects temperature, and memory **80***c* that stores plural values of the offset of signal sin each corresponding to respective one of plural values of the temperature. In this case, temperature-characteristic correction circuit **70***p* adds a value of the offset corresponding to a value of the detected temperature out of the stored plural values of the offset to signal sin.

Memory **80***c* may store plural values related to the offset of the differential signal each corresponding to respective one of plural values of the temperature. In this case, temperature-characteristic correction circuit **70***p* adds a value related to the offset corresponding to a value of the detected temperature out of the stored plural values related to the offset to signal sin.

Memory **80***c* may store plural values related to the amplitude of signal sin each corresponding to respective one of plural values of the temperature. In this case, temperature-characteristic correction circuit **70***p* adds, to signal sin, a value related to the amplitude corresponding to a value of the detected temperature out of the stored plural values related to the amplitude.

Memory **80***c* may store plural values related to the amplitude of the differential signal each corresponding to respective one of plural values of the temperature. In this case, temperature-characteristic correction circuit **70***p* adds, to signal sin, a value related to the amplitude corresponding to the detected value of the temperature out of the stored plural values related to the amplitude.

The magnetic detection elements (magneto-resistive elements **12***a* and **12***c*) and the magnetic detection elements (magneto-resistive elements **12***e* and **12***f*) may contain magneto-resistive material.

Rotation detecting device **150** (magnetic sensor **100**) that detects rotation of the object (object magnet **142**) includes magnetic detection elements (magneto-resistive elements **12***a* and **12***c*) that output signal sin, magnetic detection elements (magneto-resistive elements **12***e* and **12***f*) that output signal cos, and detection circuit **10** to which signal sin and signal cos are input. Detection circuit **10** includes temperature-characteristic correction circuit **70***p* that corrects at least one of amplitude and offset of each of signal sin and signal cos according to the temperature, and automatic correction circuit **70***e* that performs generation and update of correction values to correct signal sin and signal cos.

Detection circuit **10** may further include angle detection circuit **70***a* that outputs an angle signal indicating an angle of the object (object magnet **142**) based on signal sin and signal cos.

When the angle indicated by the angle signal changes to 0° from 360° again after changing to 0° from 360°, or when the angle indicated by the angle signal changes to 360° from 0° again after changing to 360° from 0°, automatic correction circuit **70***e* may perform at least one of the generation and the update of the correction values.

When temperature-characteristic correction circuit **70***p* operates, automatic correction circuit **70***e* does not necessarily operate.

Rotation detecting device **150** including the magnetic detection elements (magneto-resistive elements **12***a* and **12***c*) and the magnetic detection elements (magneto-resistive elements **12***e* and **12***f*) and detecting rotation of the object (object magnet **142**) corrects signals by the method below. According to the rotation of the object (object magnet **142**), signal sin and signal cos are obtained from the magnetic detection elements (magneto-resistive elements **12***a* and **12***c*) and the magnetic detection elements (magneto-resistive elements **12***e* and **12***f*), respectively. Signal sin, signal cos, and a correction value for correction are generated and updated. Rotation detecting device **150** detects that the rotation direction of the object (object magnet **142**) changes to reverse rotation direction Dr from normal rotation direction Df or that the rotation direction of an object (object magnet **142**) changes to normal rotation direction Df from reverse rotation direction Dr. When detecting that the rotation direction of the object (object magnet **142**) changes to reverse rotation direction Dr from normal rotation direction Df or that the rotation direction of the object (object magnet **142**) changes to normal rotation direction Df from reverse rotation direction Dr, rotation detecting device **150** stops the above-mentioned operation i.e., the generation and the update of correction values.

The angle signal indicating an angle of the object (object magnet **142**) may be obtained from signal sin and signal cos. In this case, a direction in which the angle indicated by the angle signal changes to 0° from 360° is defined as normal rotation direction Df. A direction in which the angle changes from 0° to 360° is defined as reverse rotation direction Dr.

FIG. **8** is a block diagram of another magnetic sensor **100***a* in accordance with the embodiment. In FIG. **8**, components identical to those of magnetic sensor **100** shown in FIGS. **1**A and **1**B are denoted by the same reference numerals. Magnetic sensor **100***a* includes detection circuit **10***a* mounted on substrate **10***p* instead of detection circuit **10** of magnetic sensor **100** shown in FIG. **1**A. Detection circuit **10***a* further includes diagnostic circuits **90** and **91**, switches **110***a* and **110***b*, and resistors **112***a* and **112***b*.

End **12***a*-**2** of magneto-resistive element **12***a* and end **12***b*-**1** of magneto-resistive element **12***b* are connected to potential VS (see FIG. **1**B). End **12***c*-**2** of magneto-resistive element **12***c* and end **12***d*-**1** of magneto-resistive element **12***d* are connected to ground GND (see FIG. **1**B). End **12***a*-**1** of magneto-resistive element **12***a* is connected to detection circuit **10***a* via wiring **100***a***1**. End **12***b*-**2** of magneto-resistive element **12***b* is connected to detection circuit **10***a* via wiring **100***a***2**. End **12***c*-**1** of magneto-resistive element **12***c* is connected to detection circuit **10***a* via wiring **100***a***3**. End **12***d*-**2** of magneto-resistive element **12***d* is connected to detection circuit **10***a* via wiring **100***a***4**.

Inside detection circuit **10***a*, wiring **100***a***1** and **100***a***3** are connected to each other at node **12***ac***1**. Inside detection circuit **10***a*, end **12***a*-**1** of magneto-resistive element **12***a* and end **12***c*-**1** of magneto-resistive element **12***c* are connected to each other at node **12***ac***1** via wirings **100***a***1** and **100***a***3**. Node **12***ac***1** constitutes a midpoint of bridge circuit WB**1**. A signal at node **12***ac***1** is input to amplifier **14***b* to be amplified, and then, input to differential amplifier **16***a*.

Inside detection circuit **10***a*, wirings **100***a***2** and **100***a***4** are connected to each other at node **12***bd***1**. Inside detection circuit **10***a*, end **12***b*-**2** of magneto-resistive element **12***b* and end **12***d*-**2** of magneto-resistive element **12***d* are connected to each other at node **12***bd***1** via wirings **100***a***2** and **100***a***4**. Node **12***bd***1** constitutes another midpoint of bridge circuit WB**1**. A signal at node **12***bd***1** is input to amplifier **14***a* to be amplified, and then, input to differential amplifier **16***a*.

End **12***e*-**2** of magneto-resistive element **12***e* and end **12***f*-**1** of magneto-resistive element **12***f* are connected to potential VC (see FIG. **1**B). End **12***g*-**2** of magneto-resistive element **12***g* and end **12***h*-**1** of magneto-resistive element **12***h* are connected to ground GND (see FIG. **1**B). End **12***e*-**1** of magneto-resistive element **12***e* is connected to detection circuit **10***a* via wiring **100***b***1**. End **12***f*-**2** of magneto-resistive element **12***f* is connected to detection circuit **10***a* via wiring **100***b***2**. End **12***g*-**1** of magneto-resistive element **12***g* is connected to detection circuit **10***a* via wiring **100***b***3**. End **12***h*-**2** of magneto-resistive element **12***h* is connected to detection circuit **10***a* via wiring **100***b***4**.

End **12***e*-**1** of magneto-resistive element **12***e* is connected to detection circuit **10***a* via wiring **100***b***1**. End **12***f*-**2** of magneto-resistive element **12***f* is connected to detection circuit **10***a* via wiring **100***b***2**. End **12***g*-**1** of magneto-resistive element **12***g* is connected to detection circuit **10***a* via wiring **100***b***3**. End **12***h*-**2** of magneto-resistive element **12***h* is connected to detection circuit **10***a* via wiring **100***b***4**.

Inside detection circuit **10***a*, wirings **100***b***1** and **100***b***3** are connected to each other at node **12***eg***1**. Inside detection circuit **10***a* on substrate **10***p*, end **12***e*-**1** of magneto-resistive element **12***e* and end **12***g*-**1** of magneto-resistive element **12***g* are connected to each other at node **12***eg***1** via wirings **100***b***1** and **200***b***3**. Node **12***eg***1** constitutes a midpoint of bridge circuit WB**2**. A signal at node **12***eg***1** is input to amplifier **14***d* to be amplified, and then, input to differential amplifier **16***b*.

Inside detection circuit **10***a*, wirings **100***b***2** and **100***b***4** are connected to each other at node **12***fh***1**. Inside detection circuit **10***a*, end **12***f*-**2** of magneto-resistive element **12***f* and end **12***h*-**2** of magneto-resistive element **12***h* are connected to each other at node **12***fh***1**. Node **12***fh***1** constitutes another midpoint of bridge circuit WB**2**. A signal at node **12***fh***1** is input to amplifier **14***c* to be amplified, and then, input into differential amplifier **16***b*.

Wirings **100***a***1** to **100***a***4** and wirings **100***b***1** to **100***b***4** are bonding wires, such as metal wires employed for wire bonding.

Magnetic sensor **100***a* can detect disconnection of wirings **100***a***1** to **100***a***4** and wirings **100***b***1** to **100***b***4** which connect detection circuit **10***a* to magneto-resistive element **12**. The operation will be described below.

In a normal operation, i.e., when none of wirings **100***a***1** to **100***a***4** and **100***b***1** to **100***b***4** are disconnected, the potentials of nodes **12***ac***1** **12***bd***1**, **12***eg***1**, and **12***fh***1** being signals output from magneto-resistive element **12** are substantially equal to potentials of the midpoints. As a result, outputs of amplifiers **14***a* to **14***d*, differential amplifiers **16***a* and **16***b*, and AD converter **18***a* are substantially equal to the potentials of the midpoints. On the other hand, if a wiring out of wirings **100***a***1** to **100***a***4** and wirings **100***b***1** to **100***b***4** is disconnected, a node out of nodes **12***ac***1**, **12***bd***1**, **12***eg***1**, and **12***fh***1** connected to the disconnected wiring becomes either one of potential VS, potential VC, or a ground potential. Potential VS and potential VC are fixed potentials. Accordingly, the outputs of amplifiers **14***a* to **14***d*, differential amplifiers **16***a* and **16***b*, and AD converters **18***a* and **18***b* are fixed to have either one of potential VS, potential VC, or the ground potential, which are fixed potential. As a result, when detecting that the output of AD converter **18***a* or AD converter **18***b* deviates from a predetermined normal operation range, diagnostic circuit **90** determines that magnetic sensor **100***a* is in an abnormal operation, and then, outputs an abnormal signal. This configuration can detect the disconnection of wirings connecting magneto-resistive element **12** to detection circuit **10***a*.

When detecting that the output of differential amplifier **16***a* or **16***b*, rather than AD converter **18***a* or **18***b*, deviates from the predetermined normal operation range, diagnostic circuit **90** determines that magnetic sensor **100***a* is in an abnormal operation, and may output an abnormal signal.

Bridge circuit WB**1** constituted by magneto-resistive elements **12***a* to **12***b*, and bridge circuit WB**2** constituted by magneto-resistive elements **12***e* to **12***h* are provided on substrate **12***p*. Detection circuit **10***a* is provided on substrate **10***p*. The midpoints constituted by nodes **12***ac***1** and **12***bd***1** of bridge circuit WB**1** are provided on substrate **10***p*. The midpoints constituted by nodes **12***eg***1** and **12***fh***1** of bridge circuit WB**2** are provided on substrate **10***p*.

Magnetic sensor **100***a* can detect abnormalities in resistances of magneto-resistive element **12**. The operation will be described below.

Switch **110***a* has common end **110***a***3**, and branch ends **110***a***1** and **110***a***2**. Switch **110***a* can connect common end **110***a***3** electively or exclusively to branch end **110***a***1** and branch end **110***a***2**. Common end **110***a***3** of switch **110***a* is directly connected to node **12***ab* of magneto-resistive element **12**. Branch end **110***a***1** is directly connected to regulator **60***a*. Branch end **110***a***2** is connected to regulator **60***a* through resistor **112***a*. Resistor **112***a* is connected in series with branch end **110***a***2** and regulator **60***a*. By disconnecting common end **110***a***3** of switch **110***a* from branch end **110***a***2** and connecting common end **110***a***3** to branch end **110***a***1**, switch **110***a* constitutes current path **112***a***1** that supplies potential VS to magneto-resistive element **12**. By disconnecting common end **110***a***3** of switch **110***a* from branch end **110***a***1** and connecting common end **110***a***3** to branch end **110***a***2**, switch **110***a* constitutes current path **112***a***2** that supplies potential VS to magneto-resistive element **12**. Current path **112***a***2** has a larger resistance than current path **112***a***1**.

Switch **110***b* has common end **110***b***3** and branch ends **110***b***1** and **110***b***2**. Switch **110***b* can connect common end **110***b***3** selectively or exclusively to branch end **110***b***1** and branch end **110***b***2**. Common end **110***b***3** of switch **110***b* is directly connected to node **12***ef* of magneto-resistive element **12**. Branch end **110***b***1** is directly connected to regulator **60***a*. Branch end **110***b***2** is connected to regulator **60***a* through resistor **112***b*. Resistor **112***b* is connected in series with branch end **110***b***2** and regulator **60***a*. By disconnecting common end **110***b***3** of switch **110***b* from branch end **110***b***2** and connecting common end **110***b***3** to branch end **110***b***1**, switch **110***b* constitutes current path **112***b***1** that supplies potential VC to magneto-resistive element **12**. By disconnecting common end **110***b***3** of switch **110***b* from branch end **110***b***1** and connecting common end **110***b***3** to branch end **110***b***2**, switch **110***b* constitutes current path **112***b***2** that supplies potential VS to magneto-resistive element **12**. Current path **112***b***2** has a larger resistance than current path **112***b***1**.

Switches **110***a* and **110***b* can switch a state of magneto-resistive element **12** between a state where magneto-resistive element **12** is connected to regulator **60***a* of detection circuit **10***a* through resistors **112***a* and **112***b* and a state where magneto-resistive element **12** is directly connected to regulator **60***a* without through resistors **112***a* and **112***b*. In the normal operation, i.e., when no abnormalities are detected in the resistances of magneto-resistive element **12**, switches **110***a* and **110***b* select current path **112***a***1** and **112***b***1** in which magneto-resistive element **12** is directly connected to regulator **60***a*. When the resistances of magneto-resistive element **12** are diagnosed, switches **110***a* and **110***b* select current path **112***a***2** and **112***b***2** in which magneto-resistive element **12** is connected to regulator **60***a* through resistors **112***a* and **112***b*. Diagnostic circuit **91** is connected to regulator **60***a*, and measures a voltage across both ends of each of resistors **112***a* and **112***b* or currents **112***a* and **112***b* flowing through resistors **112***a* and **112***b*. If magneto-resistive element **12** has a normal resistance and wirings supplying potential VS and VC are not disconnected, currents **1112***a* and **1112***b* flowing through resistors **112***a* and **112***b* is within a predetermined normal range. If a fault occurs in magneto-resistive element **12** to cause abnormalities in resistance, or if the wirings supplying potential VS and VC is disconnected, currents **112***a* and **112***b* flowing through resistors **112***a* and **112***b* deviate from the predetermined normal range. When currents **112***a* and **112***b* deviate from the normal range, diagnostic circuit **91** determines that abnormalities occur, and outputs an abnormal signal. With the configuration, abnormalities in resistance of magneto-resistive element **12** and disconnection of wirings for supplying potential VS and VC can be detected. Even when sheet resistance of magneto-resistive element **12** changes, i.e., resistance of four magneto-resistive elements which constitute bridge circuits WB**1** and WB**2** changes by the same amount at the same time, abnormalities can be detected based on currents **112***a* and **112***b*, as mentioned above.

The period of time when current path **112***a***2** connected to regulator **60***a* through resistor **112***a* is elected, i.e., when bridge circuit WB**1** is diagnosed is preferably different from a period of time when current path **112***b***2** connected to regulator **60***a* through resistor **112***b* is selected, i.e., when bridge circuit WB**2** is diagnosed. This configuration allows the current flowing through bridge circuit WB**1** and the current flowing through bridge circuit WB**2** to be input to diagnostic circuit **91** subsequently, thereby diagnosing bridge circuits WB**1** and WB**2** without enlarging the circuit scale of diagnostic circuit **91**.

Rotation detecting device **150** (magnetic sensor **100***a*) includes substrate **12***p*, magneto-resistive elements **12***a* to **12***d* that are provided on substrate **12***p* to constitute bridge circuit WB**1**, substrate **10***p*, detection circuit **10***a* that is provided on substrate **10***p* and connected to magneto-resistive elements **12***a* to **12***d*, wiring **100***a***1** connecting between end **12***a*-**1** of magneto-resistive element **12***a* and detection circuit **10***a*, wiring **100***a***3** connecting between end **12***c*-**1** of magneto-resistive element **12***c* and detection circuit **10***a*, wiring **100***a***2** connecting between end **12***b*-**2** of magneto-resistive element **12***b* and detection circuit **10***a*, wiring **100***a***4** connecting between end **12***d*-**2** of magneto-resistive element **12***d* and detection circuit **10***a*, node **12***ac***1** that is provided on substrate **10***p* and combines a signal on wiring **100***a***1** with a signal on wiring **100***a***3**, and node **12***bd***1** that is provided on substrate **10***p* and combines a signal on wiring **100***a***2** with a signal on wiring **100***a***4**. Detection circuit **10***a* includes amplifier **14***b* that is provided on substrate **10***p* and amplifies a signal at node **12***ac***1**, and amplifier **14***a* that is provided on substrate **10***p* and amplifies a signal at node **12***bd***1**.

Node **12***ac***1** and node **12***bd***1** constitute a midpoint (node **12***ac***1**) and a midpoint (node **12***bd***1**) of bridge circuit WB**1**, respectively.

Wirings **100***a***1** to **100***a***4** may be bonding wires.

Detection circuit **10***a* may further include differential amplifier **16***a* that amplifies a difference between a signal from amplifier **14***b* and a signal from amplifier **14***a*.

Detection circuit **10***a* may further include diagnostic circuit **90** to which a signal from differential amplifier **16***a* is input.

Diagnostic circuit **90** may output an abnormal signal when an output from differential amplifier **16***a* deviates from a predetermined range. Detection circuit **10***a* may include analog-to-digital (AD) converter **18***a* to which a signal is input from differential amplifier **16***a*.

Diagnostic circuit **90** may output an abnormal signal when an output of AD converter **18***a* deviates from a predetermined range.

End **12***a*-**2** of magneto-resistive element **12***a* and end **12***b*-**1** of magneto-resistive element **12***b* are connected to reference potential VS. End **12***c*-**2** of magneto-resistive element **12***c* and end **12***d*-**1** of magneto-resistive element **12***d* are connected to ground GND.

Rotation detecting device **150** (magnetic sensor **100***a*) includes substrate **12***p*, magneto-resistive elements **12***a* to **12***d* that are provided on substrate **12***p* to constitute bridge circuit WB**1**, substrate **10***p*, detection circuit **10***a* that is provided on substrate **10***p* and connected to magneto-resistive elements **12***a* to **12***d*, wiring **100***a***1** connecting between end **12***a*-**1** of magneto-resistive element **12***a* and detection circuit **10***a*, wiring **100***a***2** connecting between end **12***b*-**2** of magneto-resistive element **12***b* and detection circuit **10***a*, wiring **100***a***3** connecting between end **12***c*-**1** of magneto-resistive element **12***c* and detection circuit **10***a*, wiring **100***a***4** connecting between end **12***d*-**2** of magneto-resistive element **12***d* and detection circuit **10***a*. A midpoint (node **12***ac***1**) and a midpoint (node **12***bd***1**) of bridge circuit WB**1** are provided on substrate **10***p*.

Detection circuit **10***a* may include amplifier **14***b* that amplifies a signal at the midpoint (node **12***ac***1**), amplifier **14***a* that amplifies a signal at the midpoint (node **12***bd***1**), and differential amplifier **16***a* that amplifies a difference between a signal from amplifier **14***b* and a signal from amplifier **14***a*.

Detection circuit **10***a* may further include diagnostic circuit **90** to which a signal from differential amplifier **16***a* is input.

Detection circuit **10***a* may further include analog-to-digital (AD) converter **18***a* to which a signal is input from differential amplifier **16***a*, and diagnostic circuit **90** to which an output of AD converter **18***a* is input.

End **12***a*-**2** of magneto-resistive element **12***a* and end **12***b*-**1** of magneto-resistive element **12***b* are connected to reference potential VS. End **12***c*-**2** of magneto-resistive element **12***c* and end **12***d*-**1** of magneto-resistive element **12***d* are connected to ground GND.

Magnetic sensor **100***a* includes magneto-resistive element **12***a* that outputs signal sin+, magneto-resistive element **12***e* that outputs signal cos−, and detection circuit **10***a* to which signal sin+ and signal cos− are input. Detection circuit **10***a* includes regulator **60***a* that supplies potential VS and VC to magneto-resistive elements **12***a* and **12***e*, respectively, current path **112***a***1** that electrically connects magneto-resistive element **12***a* to regulator **60***a*, current path **112***a***2** with resistor **112***a* that electrically connects magneto-resistive element **12***a* to regulator **60***a*, current path **112***b***1** that electrically connects magneto-resistive element **12***e* to regulator **60***a*, current path **112***b***2** with resistor **112***b* that electrically connects magneto-resistive element **12***e* to regulator **60***a*, switch **110***a* that switches between current path **112***a***1** and current path **112***a***2**, switch **110***b* that switches between current path **112***b***1** and current path **112***b***2**, and diagnostic circuit **91** connected to current path **112***a***2** and current path **112***b***2**.

Diagnostic circuit **91** is connected to both ends of resistor **112***a* and both ends of resistor **112***b*.

Magneto-resistive element **12***a* are combined with three other magneto-resistive elements **12***b* to **12***c* to constitute bridge circuit WB**1**, and magneto-resistive element **12***e* are combined with three other magneto-resistive elements **12***f* to **12***h* to constitute bridge circuit WB**2**. Magneto-resistive element **12***e* and magneto-resistive element **12***a* are made of the same material, and magneto-resistive element **12***a* coincides with a configuration in which magneto-resistive element **12***e* is rotated at **450**.

Magnetic sensor **100***a* includes magneto-resistive element **12***a* that outputs signal sin+, and detection circuit **10***a* to which signal sin+ is input. Detection circuit **10***a* includes regulator **60***a* that supplies potential VS to magneto-resistive element **12***a*, current path **112***a***1** that electrically connects magneto-resistive element **12***a* to regulator **60***a*, current path **112***a***2** with resistor **112***a* that electrically connects magneto-resistive element **12***a* to regulator **60***a*, switch **110***a* that switches between current path **112***a***1** and current path **112***a***2**, and diagnostic circuit **91** connected to current path **112***a***2**.

Diagnostic circuit **91** is connected to both ends of resistor **112***a*.

Rotation detecting device **150** includes magnetic sensor **100***a*, object magnet **142** that generates a magnetic field detected by magnetic sensor **100***a*, rotation shaft **144** to which object magnet **142** is attached, bearing **146** for supporting rotation shaft **144**, and motor **158** that rotates rotation shaft **144**.

Magnetic sensor **100***a* includes magneto-resistive element **12***a* that outputs signal sin+, magneto-resistive element **12***e* that outputs signal cos−, and regulator **60***a* connected to magneto-resistive elements **12***a* and **12***e*. Magnetic sensor **100***a* can be diagnosed by the following method. Potential VS is supplied to magneto-resistive element **12***a* from regulator **60***a* through current path **112***a***1**. Potential VS is supplied to magneto-resistive element **12***a* from regulator **60***a* through current path **112***a***2** having a larger resistance than current path **112***a***1** so as to cause current **112***a* to flow through magneto-resistive element **12***a*. Potential VC is supplied to magneto-resistive element **12***e* from regulator **60***a* through current path **112***b***1**. Potential VC is supplied to magneto-resistive element **12***e* from regulator **60***a* through current path **112***b***2** having a larger resistance than current path **112***b***1** so as to cause current **112***b* to flow through magneto-resistive element **12***e*. When current **112***a* deviates from a predetermined range, it is determined that magneto-resistive element **12***a* is in an abnormal operation. When current **112***b* deviates from a predetermined range, it is determined that magneto-resistive element **12***e* is in an abnormal operation.

A period of time when current **112***b* flows through magneto-resistive element **12***e* may be different from a period of time when current **112***a* flows through magneto-resistive element **12***a*. A period of time when it is determined that magneto-resistive element **12***e* is in the abnormal operation may be different from a period of time when it is determined that magneto-resistive element **12***a* is in the abnormal operation.

FIG. **9** is a top view of magnetic sensor **100** (**100***a*). FIG. **10** is a side view of magnetic sensor **100** (**100***a*). In FIG. **9**, the structure of magnetic sensor **100** (**100***a*) is partially omitted. In magnetic sensor **100** (**100***a*) shown in FIG. **9**, each of Hall elements **40***a* and **40***b* is a longitudinal type of Hall element that detects a magnetic field parallel to substrate **10***p* on which detection circuit **10** is provided.

Magnetic sensor **100** (**100***a*) includes magneto-resistive element **12**, detection circuit **10**, lead frame **130**, wire **134**, sealing resin **136**, and terminal **132**. Magneto-resistive elements **12***a* to **12***d* constitute magneto-resistive element group **12***x* that forms bridge circuit WB**1**.

Magneto-resistive elements **12***e* to **12***h* constitute magneto-resistive element group **12***y* that forms bridge circuit WB**2**. Magneto-resistive element **12** and detection circuit **10** are disposed on lead frame **130**. Sealing resin **136** seals magneto-resistive element **12**, detection circuit **10**, and lead frame **130**. Terminal **132** extends from sealing resin **136** to connect detection circuit **10** electrically to the outside.

Straight line L1 passes substantially through center **12***xc* of magneto-resistive element group **12***x* constituted by magneto-resistive elements **12***a* to **12***d* and center **12***yc* of magneto-resistive element group **12***y* constituted by magneto-resistive elements **12***e* to **12***h*. Hall elements **40***a* and **40***b* are arranged symmetrically to each other with respect to straight line L**1**. In more detail, a direction of a magnetic field detected by Hall elements **40***a* and **40***b* inclines by 45° with respect to straight line L**1**.

Each of magneto-resistive elements **12***a* to **12***d* is made of magnetic resistance pattern **12***t* slenderly extending perpendicularly to a direction of the magnetic field to be detected. Magnetic resistance pattern **12***t* of magneto-resistive element **12***a* extends slenderly along straight line L**4**. Magnetic resistance pattern **12***t* of magneto-resistive element **12***c* extends slenderly along straight line L**6**. Straight lines L**4** and L**6** extend symmetrically to each other with respect to straight line L**1**. Straight line L**4** inclines by 45° with respect to straight line L**1**. Straight line L**6** inclines by 45° with respect to straight line L**1**. Straight line L**4** inclines by 90° with respect to straight line L**6**. Each of magneto-resistive elements **12***e* to **12***h* is made of magnetic resistance pattern **12***s* slenderly extending perpendicularly to a direction of the magnetic field to be detected. Magnetic resistance patterns **12***t* and **12***s* are made of magneto-resistive material that has a magneto-resistive effect. Hall elements **40***a* and **40***b* detect magnetic field along straight lines L**3** and L**5** passing substantially through the respective centers of Hall elements **40***a* and **40***b*. Straight line L**3** passing substantially through the center of Hall element **40***a* is parallel to magnetic resistance pattern **12***t* of any one of magneto-resistive elements **12***a* to **12***d*. Straight line L**3** is parallel to magnetic resistance pattern **12***t* of magneto-resistive element **12***a*, and therefore, is parallel to straight line L**4**. Straight line L**5** passing substantially through the center of Hall element **40***b* is parallel to magnetic resistance pattern **12***t* of any one of magneto-resistive elements **12***a* to **12***d*. Straight line L**5** is parallel to magnetic resistance pattern **12***t* of magneto-resistive element **12***c*, and therefore, is parallel to straight line L**6**.

Hall element **40***b* has a configuration identical to that of Hall element **40***a* rotating by 90°. Magneto-resistive element **12***b* has a configuration identical to that of magneto-resistive element **12***a* rotating by 90°. Magneto-resistive element **12***d* has a configuration identical to that of magneto-resistive element **12***c* rotating by 90°. Magneto-resistive element **12***c* has a configuration identical to that of magneto-resistive element **12***a* rotating by 90°. Magneto-resistive element **12***d* has a configuration identical to that of magneto-resistive element **12***b* rotating by 90°. Each of Hall elements **40***a* and **40***b* is a longitudinal type of Hall element that detects a magnetic field parallel to substrate **10***p* on which detection circuit **10** is provided. Accordingly, to easily obtain a magnetic field parallel to substrate **10***p*, Hall elements **40***a* and **40***b* are preferably provided near the center of substrate **10***p*. Thus, Hall elements **40***a* and **40***b* can detect the angle accurately.

In accordance with the embodiment, magnetic sensor **100** (**100***a*) is attached to motor **158** assisting steering wheel **152** and steering shaft **154**, but not limited to this. For instance, magnetic sensor **100** (**100***a*) may be used for detecting a position of a shift lever of a vehicle. In other words, magnetic sensor **100** (**100***a*) may be used independently as a stand-alone unit.

Diagnostic circuit **90** may be a part of processing unit **70**.

As described above, magnetic sensor **100** includes substrate **12***p*, magneto-resistive element group **12***x* that is provided on substrate **12***p* and constituted by plural magneto-resistive elements **12***a* to **12***d* constituting bridge circuit WB**1**, magneto-resistive element group **12***y* that is provided on substrate **12***p* and constituted by plural magneto-resistive elements **12***e* to **12***h* constituting bridge circuit WB**2**, substrate **10***p*, Hall elements **40***a* and **40***b* provided on substrate **10***p*, and detection circuit **10** that is provided on substrate **10***p* and receives a signal from magneto-resistive element group **12***x*, a signal from magneto-resistive element group **12***y*, a signal from Hall element **40***a*, and a signal from Hall element **40***b*. Each of Hall elements **40***a* and **40***b* is a longitudinal type Hall element detecting a magnetic field parallel to substrate **10***p*. Hall element **40***a* and Hall element **40***b* are arranged symmetrically to each other with respect to straight line L**1**. Straight line L**1** passes substantially through center **12***xc* of magneto-resistive element group **12***x* and center **12***yc* of magneto-resistive element group **12***y*.

A direction of the magnetic field detected by Hall element **40***a* may incline by 45° with respect to straight line L**1**. A direction of the magnetic field detected by Hall element **40***b* may incline by 45° with respect to straight line L**1**.

Magneto-resistive element **12***a* out of plural magneto-resistive elements **12***a* to **12***d* of magneto-resistive element group **12***x* includes magnetic resistance pattern **12***t* made of magneto-resistive material. Magneto-resistive element **12***b* out of plural magneto-resistive elements **12***a* to **12***d* of magneto-resistive element group **12***x* includes magnetic resistance pattern **12***t* made of magneto-resistive material. Straight line L**3** passing substantially through the center of Hall element **40***a* may be parallel to magnetic resistance pattern **12***t* of magneto-resistive element **12***a*. Straight line L**4** passing substantially through the center of Hall element **40***b* may be parallel to magnetic resistance pattern **12***t* of magneto-resistive element **12***b*.

Hall elements **40***a* and **40***b* are made of the same material. Hall element **40***a* has a configuration identical to that of Hall element **40***b* rotating by 90°.

Plural magneto-resistive elements **12***a* to **12***d* of magneto-resistive element group **12***x* are made of the same material. Magneto-resistive element **12***a* out of plural magneto-resistive elements **12***a* to **12***d* of magneto-resistive element group **12***x* has a configuration identical to that of magneto-resistive element **12***b* out of magneto-resistive elements **12***a* to **12***d* of magneto-resistive element group **12***x* which rotates by 90°.

As described above, magnetic sensor **100** includes magneto-resistive element group **12***x* constituted by plural magneto-resistive elements **12***a* to **12***d*, magneto-resistive element group **12***y* constituted by plural magneto-resistive elements **12***e* to **12***h*, Hall element **40***a*, Hall element **40***b*, detection circuit **10** to which signals from magneto-resistive element groups **12***x* and **12***y* and signals from Hall elements **40***a* and **40***b* are input. Plural magneto-resistive elements **12***a* to **12***d* of magneto-resistive element group **12***x* include magneto-resistive element **12***a* including magnetic resistance pattern **12***t*, and magneto-resistive element **12***b* including magnetic resistance pattern **12***t*. Straight line L**3** passing substantially through the center of Hall element **40***a* is parallel to magnetic resistance pattern **12***t* of magneto-resistive element **12***a*. Straight line L**5** passing substantially through the center of Hall element **40***b* is parallel to magnetic resistance pattern **12***t* of magneto-resistive element **12***b*.

Hall element **40***a* may be arranged such that Hall element **40***a* inclines by 45° with respect to straight line L**1** passing substantially through center **12***xc* of magneto-resistive element group **12***x* and center **12***yc* of magneto-resistive element group **12***y*. Hall element **40***b* may be arranged such that Hall element **40***b* inclines by 45° with respect to straight line L**1**.

Hall elements **40**a and **40**b may be symmetrical to each other with respect to straight line L**1** passing substantially through center **12**xc of magneto-resistive element group **12**x and center **12**yc of magneto-resistive element group **12**y.

Magneto-resistive element group **12**x constitutes bridge circuit WB**1**, and magneto-resistive element group **12**y constitutes bridge circuit WB**2**.

FIG. **11** is a top view of still another magnetic sensor **100**b in accordance with the exemplary embodiment. FIG. **12** is a cross-sectional view of magnetic sensor **100**b along line XII-XII shown in FIG. **11**. In FIGS. **11** and **12**, components identical to those of the magnetic sensor shown in FIGS. **1**A to **10** are denoted by the same reference numerals. In FIG. **12**, a structure of magnetic sensors **100**b is partially omitted. Magnetic sensor **100**b includes two magnetic sensors **100** (**100**a), and includes two magneto-resistive elements **121** and **122** each having the same structure as magneto-resistive element **12** shown in FIGS. **1**A and **1**B. Each of magneto-resistive elements **121** and **122** has the same substrate as substrate **12**p shown in FIG. **8**. Magneto-resistive element **121** includes magneto-resistive element group **121**a and magneto-resistive element group **121**b. Magneto-resistive element group **121**a includes magneto-resistive elements **12**a to **12**d shown in FIGS. **1**A and **1**B. Magneto-resistive element group **121**b includes magneto-resistive elements **12**e to **12**h shown in FIGS. **1**A and **1**B. Similarly, magneto-resistive element **122** includes magneto-resistive element group **122**a and magneto-resistive element group **122**b. Magneto-resistive element group **122**a includes magneto-resistive elements **12**a to **12**d shown in FIGS. **1**A and **1**B. Magneto-resistive element group **122**b includes magneto-resistive elements **12**e to **12**h shown in FIGS. **1**A and **1**B. In accordance with the exemplary embodiment, detection circuit **10**c is provided on an upper surface of substrate **10**c**1** while detection circuit **10**d is provided on an upper surface of substrate **10**d**1**.

Magnetic sensor **100**b includes magneto-resistive elements **121** and **122**, detection circuits **10**c and **10**d, substrates **10**c**1** and **10**d**1**, die pad **130**, wire **134**, sealing resin **138**, and leads **132**a and **132**b.

Magneto-resistive elements **121** and **122**, and substrates **10**c**1** and **10**d**1** are mounted onto die pad **130**.

Sealing resin **138** seals magneto-resistive elements **121** and **122**, substrates **10**c**1** and **10**d**1**, and die pad **130**.

Leads **132**a and **132**b extend from sealing resin **138** and electrically connected to the outside.

A signal from magneto-resistive element **121** is input to detection circuit **10**c. The structure and operation of detection circuit **10**c are the same as the structure and operation of detection circuit **10** (**10**a).

A signal from magneto-resistive element **122** is input to detection circuit **10**d. The structure and operation of detection circuit **10**d are the same as the structure and operation of detection circuit **10** (**10**a).

As shown in FIG. **11**, magneto-resistive elements **121** and **122** are symmetrical to each other about straight line L**11**. Alternatively, straight line L**12** passes through the center of magneto-resistive element group **121**a, the center of magneto-resistive element group **121**b, the center of magneto-resistive element group **122**a, and the center of magneto-resistive element group **122**b. Magneto-resistive elements **121** and **122** increase redundancy of the sensor, thereby improving the reliability.

Substrate **10**c**1** has end surface **10**c**11** that faces substrate **10**d**1**. Magneto-resistive element **121** has end surface **1211** that faces magneto-resistive element **122**. End surface **1211** of magneto-resistive element **121** is flush with end surface **10**c**11** of substrate **10**c**1**. In other words, end surface **1211** of magneto-resistive element **121** and end surface **10**c**11** of substrate **10**c**1** are located on straight line L**13** when viewed from above.

Substrate **10**d**1** has end surface **10**d**11** that faces substrate **10**c**1**. Magneto-resistive element **122** has end surface **1221** that faces magneto-resistive element **121**. End surface **1221** of magneto-resistive element **122** is flush with end surface **10**d**11** of substrate **10**d**1**. In other words, end surface **1221** of magneto-resistive element **122** and end surface **10**d**11** of substrate **10**d**1** are located on straight line L**14** when viewed from above.

Detection circuit **10**c and detection circuit **10**d include electrode groups **126**a and **126**b each including plural electrodes to be electrically connected to a magneto-resistive element or a lead. The electrodes of electrode groups **126**a and **126**b are arranged in parallel with straight line L**12**. The electrodes are also arranged in parallel with straight lines L**15** and L**16** separated away from straight line L**12**. Electrode groups **126**a and **126**b and wires connected to the electrode groups are separated away from straight line L**12**, i.e., the center of the magneto-resistive elements. This configuration prevents interference from electrode groups **126**a and **126**b and the wires connected thereto, thereby improving accuracy of the magnetic sensor.

FIG. **13** is a cross-sectional view of further magnetic sensor **100**c in accordance with the exemplary embodiment. In FIG. **13**, components identical to those of magnetic sensor **100**b shown in FIGS. **11** and **12** are denoted by the same reference numerals.

Magnetic sensor **100**c includes magneto-resistive elements **121** and **122**, substrates **10**c**1** and **10**d**1**, die pad **130**, sealing resin **138**, wire **134** (FIG. **11**), and leads **132**a and **132**b (FIG. **11**).

In magnetic sensor **100**c, magneto-resistive element **122** is disposed on an upper surface of magneto-resistive element **121**. The center of magneto-resistive element **121** coincides substantially with the center of magneto-resistive element **122** when viewed from above. In other words, straight line C**11** passes through the center of magneto-resistive element **121** and the center of magneto-resistive element **122**. This configuration allows the center of magneto-resistive element **121** to be close to the center of magneto-resistive element **122**. Therefore, the signals obtained from magneto-resistive element **121** and magneto-resistive element **122** can preferably be substantially the same.

In magnetic sensor **100**c, substrate **121** includes portion **136** that does not overlap magneto-resistive element **122** when viewed from above. In other words, a width of the substrate constituting magneto-resistive element **121** is larger than a width of the substrate constituting magneto-resistive element **122**. Portion **136** is provided to secure an area for wiring. Portion **136** allows the center of magneto-resistive element **121** to substantially coincide with the center of magneto-resistive element **122** when viewed from above. Therefore, the signals obtained from magneto-resistive elements **121** and **122** can preferably be substantially the same.

FIG. **14** is a cross-sectional view of further magnetic sensor **100**d in accordance with the exemplary embodiment. In FIG. **14**, components identical to those of magnetic sensor **100**c shown in FIG. **13** are denoted by the same reference numerals. Magnetic sensor **100**d shown in FIG. **14** includes die pads **130**a and **130**b, instead of die pad **130** of magnetic sensor **100**c shown in FIG. **13**. Substrate **10**c**1** is provided on an upper surface of die pad **103**a. Substrate **10**d**1** is provided on an upper surface of die pad **130**b. Magnetic sensor **100**b

shown in FIG. **12** may further include two die pads **130***a* and **130***b* each having a corresponding one of upper surfaces on which substrates **10***c***1** and **10***d***1** are provided, instead of die pad **130**.

FIGS. **15** and **16** are perspective views of magnetic sensor **100***c* shown in FIG. **13**. In FIG. **15**, the structure of magnetic sensor **100***c* shown in FIG. **13** is partially omitted or simplified. In FIG. **16**, the structure of magnetic sensor **100***c* shown in FIG. **15** is partially omitted.

Magneto-resistive element **121** includes electrode group **127***a* constituted by plural electrodes. Magneto-resistive element **122** includes electrode group **127***b* constituted by plural electrodes. Electrode group **127***a* is provided on portion **136** of magneto-resistive element **121** that is exposed from magneto-resistive element **122**. The electrodes of electrode group **127***a* are arranged along straight line L**17**.

Electrode group **127***b* which is constituted by the electrodes is provided on magneto-resistive element **122**. The electrodes of electrode group **127***b* are arranged along straight line L**18**. Straight line L**17** is parallel with straight line L**18**.

FIG. **17**A is a front view of magneto-resistive element **12** of magnetic sensor **100***a* shown in FIG. **8**. FIG. **17**B is a cross-sectional view of magneto-resistive element **12** along line **17**B-**17**B shown in FIG. **17**A. The structure of magneto-resistive element **12** shown in FIG. **17**B is applicable not only to magnetic sensor **100***a* shown in FIG. **8** but also to the magnetic sensor shown in FIGS. **1**A and **1**B.

FIG. **17**B shows a cross-section of magneto-resistive element **12***h*. Magneto-resistive element **12***h* includes silicon substrate **181**, insulating layer **182** stacked on silicon substrate **181** in laminating direction D**12**, magneto-resistive (MR) layer **185** stacked on insulating layer **182** in laminating direction D**12**, adhesion layer **187** stacked on MR layer **185** in laminating direction D**12**, wiring layer **189** stacked on adhesion layer **187** in laminating direction D**12**, protection layer **183** stacked on MR layer **185** in laminating direction D**12**, and protection layer **184** stacked on protection layer **183** in laminating direction D**12**. Insulating layer **182** is made of silicon oxide, such as silicon dioxide. Adhesion layer **187** is made of titanium. FIG. **17**B shows a cross-section of magneto-resistive element **12***h* along laminating direction D**12**.

Wiring layer **189** is a wiring line for electrical connection between MR layer **185** and detection circuit **10**, and is made of, e.g. gold (Au). Wiring layer **189** includes a portion exposed from protection layer **184**, and is electrically connected to the outside. Adhesion layer **187** bonds wiring layer **189** to MR layer **185**.

Protection layer **183** protects MR layer **185**. An upper surface and a side surface of MR layer **185** are covered with protection layer **183**. In accordance with the exemplary embodiment, film thickness T**2** of protection layer **183** between MR layer **185** and protection layer **184** is equal to or larger than 1.5 nm. Film thickness T**1** of MR layer **185** is equal to or smaller than 15 nm. Ratio T**1**/T**2** of film thickness T**1** of MR layer **185** to film thickness T**2** of protection layer **183** is larger than 1/10. Protection layer **183** allows protection layer **184** to be tightly bonded to MR layer **185**, thereby improving reliability to humidity. In the case that protection layer **184** has a high Young's modulus, protection layer **183** prevents MR layer **185** from receiving an influence due to a stress of protection layer **184**.

Protection layer **184** is provided on protection layer **183**, and is made of, e.g. silicon dioxide (SiO_2) or fluoride-based resin. Providing protection layer **184** prevents oxidation, which is caused by humidity of MR layer **185** or oxygen in the air at high temperature, and protects MR layer **185** from a mechanical crack, corrosion that is caused by direct contact with all other chemical substances.

A nickel iron alloy is sputtered on insulating layer **182** to form (deposit) MR layer **185**. More specifically, while vacuum is increased, a nickel iron alloy is sputtered at low gas pressure with high kinetic energy applied to material atoms of the nickel iron alloy, thereby providing thin and homogeneous MR layer **185**.

Width W of MR layer **185** in a direction perpendicular to laminating direction D**12** is equal to or larger than 15 μm. Film thickness T**1** of MR layer **185** in laminating direction D**12** is equal to or smaller than 15 nm. In other words, in the cross-section of magneto-resistive element **12** shown in FIG. **17**B, an aspect ratio (T**1**/W) of film thickness T**1** of MR layer **185** to width W of MR layer **185** is equal to or smaller than 1/1000. This configuration reduces magnetic anisotropy field Ha of MR layer **185**. Here, magnetic anisotropy field Ha is expressed by the following equation with constant physical property value 4πMs.

$$Ha=4\pi Ms+(T/W)$$

Magnetic anisotropy field Ha of MR layer **185** is smaller than 12 (Oe). Film thickness T**1** of MR layer **185** is equal to or smaller than 15 nm and width W of MR layer **185** is equal to or larger than 15 μm provides the relationship of the above equation. Thus, even if a rotating signal magnetic field with a magnetic field strength equal to or larger than 12 (Oe) is applied, the signal output from magneto-resistive element **12***h* is obtained as an almost ideal sine wave. Further, even if the magnetic field strength is increased to infinite, waveform and voltage of the signal output from magneto-resistive element **12***h* are not almost changed. Accordingly, if the magnetic field strength of a magnet is sufficiently high and a decrease of the signal magnetic field which is caused by a temperature change is equal to or larger than 12 (Oe), temperature characteristics of the output voltage, which depends on the magnet, can be virtually ignored, so that the circuit configuration is simplified.

FIG. **18**A is a cross-sectional view of MR layer **585** of a comparative example of a magneto-resistive element. FIG. **18**B is a cross-sectional view of MR layer **185** of magneto-resistive element **12** according to the embodiment.

After the magneto-resistive element is patterned to extend slenderly in a longitudinal direction as shown in FIG. **17**A, MR layer **585** of the comparative example shown in FIG. **18**A has a cross-section in which magnetic domain walls, each of which is a boundary between one magnetic domain and another magnetic domain, are aligned in a longitudinal direction of MR layer **585**. This structure is obtained as follows. A substrate is heated to a temperature equal to or higher than 200° C., and MR layer **585** is deposited by, e.g. ion beam deposition to have a film thickness equal to larger than 25 nm, thereby providing crystal grain C**585** with a predetermined particle diameter. Grain boundaries B**585**, each of which is a boundary between crystal grains C**585**, exist in a cross-section of MR layer **585**. This method hardly reduces the film thickness because the film thickness of MR layer **585** equal to or smaller than 25 nm provides crystal grain C**585** with an island-shape structure. In consideration of consumption current, if the resistance is increased, it will be necessary to reduce a width of MR layer **585**. As shown in the above equation, however, if the width of MR layer **585** is reduced, magnetic anisotropy field Ha increases. Thus, the sine waveform, which is obtained at the time of detecting a magnetic field angle, is distorted remarkably. This deteriorates the detection accuracy.

On the other hand, after magneto-resistive element **12** is patterned to extend slenderly in the longitudinal direction as shown in FIG. **17**A, MR layer **185** in accordance with the exemplary embodiment shown in FIG. **18**B has a cross-section in which crystal grains of a metallic material (nickel iron alloy according to the exemplary embodiment), which constitutes MR layer **185**, do not exist, i.e., grain boundaries, each of which is a boundary between the crystal grains, do not exist. MR layer **185** has magnetization anisotropy in a direction of film thickness T**1** (in another expression, laminating direction D**12**). This configuration prevents MR layer **185** from being magnetized in a direction parallel to a surface of insulating layer **182** because crystal grains are not fully formed for film thickness T**1** equal to or smaller than 15 nm, and crystal grains are not formed when sputtered at a substrate temperature equal to or lower than 25° C. In other words, when a magnetic field in a direction substantially parallel to silicon substrate **181** is applied, the direction of magnetization of MR layer **185** is easily reversed, and MR layer **185** is mostly saturated magnetically with a low magnetic field. That is, MR layer **185** is magnetized in a direction parallel to a main surface of silicon substrate **181**. This configuration reduces a superimposed amount of magnetic field strength that is changed when an angle of the magnetic field with respect to a direction substantially parallel to silicon substrate **181** is detected. This configuration provides an angle detection signal substantially consistent with the theory. The term "crystal grains do not exist" means that crystal grains do not exist in a cross-section along a direction perpendicular to the longitudinal direction of MR layer **185** shown in FIG. **17**B. Further, the term "crystal grains do not exist" does not necessarily mean that no crystal grains exist in all of cross-sections of MR layer **185**, which appear in the above cross-section, but also means that crystal grains do not exist in at least one cross-section in laminating direction D**12** of MR layer **185**. The one cross-section of MR layer **185** is a cross-section of MR layer **185** that appears in an area surrounded by a dashed line in FIG. **17**B.

In the case where magnetic sensor **100** in accordance with the exemplary embodiment is used for a rotation detection device, object magnet **142** preferably has a magnetic field (signal magnetic field) equal to or larger than 20 mT. This is because, in the case that magnetic sensor **100** in the exemplary embodiment used for an in-vehicle magnetic sensor, since a large-sized power generator, a motor, or the like is often mounted near the magnetic sensor in a vehicle, magnetic sensor **100** is likely to be affected by magnetic field variations caused by coils built in these components. Accordingly, the signal magnetic field strength to be detected is set as high as possible, thereby reducing these influences.

Magnetic sensor **100** is attached to motor **158** assisting steering wheel **152** and steering torque **154**, which are shown in FIG. **2**B, but not limited to this. Magnetic sensor **100** in accordance with the exemplary embodiment may be used, for example, for detecting a lever position of a shift lever in a vehicle. In other words, magnetic sensor **100** can be used solely and independently.

Diagnostic circuit **90** shown in FIG. **8** may be a part of processing circuit **70**.

FIG. **19** shows another magnetic sensor **100***e* in accordance with the exemplary embodiment. In FIG. **19**, structure of magnetic sensor **100***e* is partially omitted or simplified. In FIG. **19**, components identical to those of magnetic sensor **100***b* shown in FIGS. **11** and **12** are denoted by n the same reference numerals.

Magnetic sensor **100***e* includes magneto-resistive element groups **121***a* and **122***b*, substrates **10***c***1** and **10***d***1**, die pad **130**, wire **134**, sealing resin **138**, lead **132**, and substrates **201***a*, **201***b*, **201***c*, and **201***d*. As described above, each of magneto-resistive element groups **121***a* and **122***a* is constituted by magneto-resistive elements **12***a* to **12***d* while each of magneto-resistive element groups **121***b* and **122***b* is constituted by magneto-resistive elements **12***e* to **12***h*.

Magneto-resistive element group **121***a* is provided on substrate **201***a*.

Magneto-resistive element group **121***b* is provided on substrate **201***b*. Substrate **201***b* includes portions **201***b***1** and **201***b***2**. Portion **201***b***1** is thicker than substrate **201***a*. Portion **201***b***2** extends from portion **201***b* and overlaps substrate **201***a*. Magneto-resistive element group **121***b* is provided on portion **201***b***2**.

Magneto-resistive element group **122***a* is provided on substrate **201***c*. Substrate **201***c* includes portions **201***c***1** and **201***c***2**. Portion **201***c***1** is thicker than substrate **201***b*. Portion **201***c***2** extends from portion **201***c***1** and overlap substrate **201***b*. Magneto-resistive element group **122***a* is provided on portion **201***c***2**.

Magneto-resistive element group **122***b* is provided on substrate **201***d*. Substrate **201***d* includes portions **201***d***1** and **201***d***2**. Portion **201***d***1** is thicker than substrate **201***d*. Portion **201***d***2** extends from portion **201***d***1** and overlap substrate **201***d*. Magneto-resistive element group **122***b* is provided on portion **201***d***2**.

Substrates **201***a* and **201***b* are arranged along axis Y**1**. Substrates **201***c* and **201***d* are arranged along axis X**1**. Axes X**1** and Y**1** intersect perpendicularly with each other. Accordingly, at least one portion of each substrate is exposed when viewed from above. Therefore, electrode **203** for electrically connecting the substrates with detection circuit **10***c* (**10***d*) can be provided on a corresponding one of the substrates. In other words, since at least one portion of each substrate is exposed when viewed from above, electrode **203** for electrically connecting of the substrates to detection circuit **10***c* (**10***d*) can be provided on an upper surface of a corresponding one of the substrates.

Each of substrates **201***b*, **201***c*, and **201***d* is mounted on an upper surface of respective one of mounting boards. In accordance with the exemplary embodiment, the mounting boards are substrates **10***c***1** and **10***d***1** on which detection circuits **10***c* and **10***d* are provided. Each of portion **201***b***1** of substrate **201***b*, portion **201***c***1** of substrate **201***c*, and portion **201***d***1** of substrate **201***d* has a portion inclined at predetermined angle θ with respect to the upper surface of the mounting board. Angle θ ranges from 45 degrees to 55 degrees.

Substrate **201***a*, portion **201***b***2** of substrate **201***b*, portion **201***c***2** of substrate **201***c*, and portion **201***d***2** of substrate **201***d* have substantially the same thickness. Portion **201***b***2** of substrate **201***b*, portion **201***c***2** of substrate **201***c*, and portion **201***d***2** of substrate **201***d* can be formed by silicon anisotropic etching, i.e., a silicon substrate is partially removed using alkaline wet anisotropic etching liquid (for example, potassium hydrate solution (KOH), tetramethyl ammonium hydroxide solution (TMAH)).

The center of magneto-resistive element group **121***a* substantially coincides with the center of magneto-resistive element group **122***b* when viewed from above. In other words, at least one portion of magneto-resistive element group **121***a* overlaps at least one portion of magneto-resistive element group **122***b* when viewed from above. Since the center of magneto-resistive element group **121***a* substantially coincides with the center of magneto-resistive element group **121***b* when viewed from above, a phase shift between the signal sin and the signal cos can be reduced. Herein, the signal sin is output from magneto-resistive element group **121***a*, and the signal cos is output from magneto-resistive element group **121***b*. Consequently, an angle error of magnetic sensor **100***d* is reduced. This configuration reduces a phase shift between an angle signal output from magneto-resistive element groups **121***a* and **121***b* and an angle signal output from magneto-resistive element groups **122***a* and **122***b*. Therefore, the redundancy of magnetic sensor **100***d* is improved.

Magnetic sensor **100** (**100***a* to **100***e*) in accordance with the exemplary embodiment can detect an angle, but not limited to this. Magnetic sensor **100** (**100***a* to **100***e*) may detect, for example, a displacement of an object moving along a straight line. This point will be detailed below.

FIG. **20**A shows an operation of magnetic sensor **100** when magnet **142** is located on the left-hand side of magnetic sensor **100**. Herein, the displacement of magnet **142** is to be detected. Any one of magnetic sensors **100***a* to **100***e* may be used as magnetic sensor **100**.

An operation of magnetic sensor **100** shown in FIG. **20**A will be described. When magnet **142** moves in a direction of displacement axis A**142** by an amount of displacement +A, a magnetic vector angle of −90 degrees is input to magnetic sensor **100**, whereas when magnet **142** moves in the direction of displacement axis A**142** by amount of displacement −A, a magnetic vector angle of +90 degrees is input to magnetic sensor **100**. FIG. **20**B shows a relationship between a magnetic vector angle which is input to magnetic sensor **100** due to the movement in the direction of displacement axis A**142**, and the amount of displacement of magnet **142**. In FIG. **20**B, the horizontal axis represents an amount of displacement, and the vertical axis represents the vector angle. Magnetic sensor **100** performs ARCTAN calculation of output of AD converters **18***a* and **18***b* (see FIG. **1**A), which is generated by the movement of magnet **142**, to output signals according to an amount of displacement of magnet **142**. FIG. **20**C shows an output of magnetic sensor **100** and an amount of displacement of magnet **142**. In FIG. **20**C, the horizontal axis represents an amount of displacement, and the vertical axis represents an output of magnetic sensor **100**. As shown in FIG. **20**C, the output of magnetic sensor **100** changes substantially linearly with respect to the amount of displacement.

FIG. **21**A shows an operation of magnetic sensor **100** when magnet **142** is located on the right-hand side of magnetic sensor **100**. Herein, the linear displacement of magnet **142** is to be detected.

An operation shown in FIG. **21**A will be described. When magnet **142** moves in the direction of displacement axis A**142** by an amount of displacement +A, a magnetic vector angle of +90 degrees is input to magnetic sensor **100**, whereas when magnet **142** moves in the direction of displacement axis A**142** by an amount of displacement −A, a magnetic vector angle of −90 degrees is input to magnetic sensor **100**. FIG. **21**B shows a relationship between a magnetic vector angle input to magnetic sensor **100** due to the movement in the direction of displacement axis A**142**, and the amount of displacement of magnet **142**. In FIG. **21**B, the horizontal axis represents an amount of displacement, and the vertical axis represents the vector angle. Magnetic sensor **100** performs ARCTAN calculation of output of AD converters **18***a* and **18***b* (see FIG. **1**A), which is generated by the movement of magnet **142**, to output signals according to an amount of displacement of magnet **142**. FIG. **21**C shows an output of magnetic sensor **100** with respect to an amount of displacement of magnet **142**. In FIG. **21**C, the horizontal axis represents an amount of displacement, and the vertical axis represents the output of magnetic sensor **100**. As shown in FIG. **21**C, the output of magnetic sensor **100** changes substantially linearly with respect to the amount of displacement. In this way, for the arrangement shown in FIG. **20**A and the arrangement shown in FIG. **21**A, the outputs of magnetic sensor **100** are changed reversely to each other.

FIG. **22** is a schematic view of detection device **230** including magnetic sensor **100** in accordance with the exemplary embodiment. Detection device **230** includes case **231**, guide **232**, object magnet **142**, shaft **234**, and magnetic sensor **100**. Shaft **234** may be a shift lever. Any one of magnetic sensors **100***a* to **100***e* may be employed as magnetic sensor **100**.

Slit **236** is provided in case **231**.

Slit **236** includes portions S**231**, S**232**, and S**236**. Each of portions S**231** and S**232** extends slenderly along a corresponding one of straight lines L**231** and L**232** in parallel with each other. Portion S**236** connects portion S**231** to portion **232**. In FIG. **22**, slit **236** has an H-shape. Guide **232** is provided in an inner wall of slit **236**. In accordance with the exemplary embodiment, guide **232** is a recess provided in an inner wall of slit **236**.

Object magnet **142** is disposed slidably in slit **236** along guide **232**. In other words, object magnet **142** is slidable along straight line L**232** and straight line L**231**. Further, straight line L**232** and straight line L**231** are tracks along which object magnet **142** moves.

Object magnet **142** may be partially fitted into guide **232**. In the case where object magnet **142** is covered with resin, the resin may be partially fitted into guide **232**. In the case where shaft **234** is a part of a lever mechanism, a linkage mechanism connected to the lever mechanism may move the object magnet.

Shaft **234** is connected to object magnet **142**. When a user operates shaft **234**, object magnet **142** moves along guide **232**.

Magnetic sensor **100** which is attached to case **231** is disposed between straight lines L**231** and L**232**, and detects a linear displacement of object magnet **142** in response to the operations shown in FIGS. **20**A to **20**C and FIGS. **21**A to **21**C.

FIG. **23**A is a partial top view of detection device **230** shown in FIG. **22**. FIG. **23**A does not illustrate unnecessary structure for description. FIG. **23**A shows straight line L**241** located between straight lines L**231** and L**232**.

Straight line L**241** parallel to straight line L**231** is located at an equal distance from straight lines L**231** and L**232**.

In detection device **230**, straight line L**241** is located between magneto-resistive element groups **12***x* and **12***y*. In other words, magneto-resistive element **12** is provided such that straight line L**241** passes through the center of magneto-resistive element **12**. On the other hand, Hall elements **40***a* and **40***b* are provided such that straight line L**241** does not pass through Hall elements **40***a* and **40***b*. In other words, Hall elements **40***a* and **40***b* are located away from straight line L**241** by a predetermined distance.

With the configuration, in magneto-resistive element **12**, even if object magnet **142** is located on either straight line L**231** or straight line L**232**, the distance from the center of magneto-resistive element group **12***x* to straight line L**231** is identical to the distance from the center of magneto-resistive element group **12***x* to straight line, and the distances from the center of magneto-resistive element group **12***y* to straight line L**231** is identical to the distance from the center of magneto-resistive element group **12***y* to straight line L**232**. Accordingly, the signals output from the magneto-resistive element groups have almost constant intensity. For instance, a signal output from magneto-resistive element **12** in response to object magnet **142** shown in FIG. **23**A located at position PA has the same intensity as a signal output from magneto-resistive element **12** in response to object magnet **142** shown in FIG. **23**A located at position PC. In other words, even if object magnet **142** is located away from magnetic sensor **100** in either direction, i.e., on the right-hand side or the left-hand side of magnetic sensor **100**, magnetic sensor **100** can detect the position of object magnet **142** accurately.

FIG. **23**B shows outputs of Hall elements **40***a* and **40***b*. In FIG. **23**B, the vertical axis represents the outputs of Hall elements **40***a* and **40***b*, and the horizontal axis represents the position of magnet **142** in a direction of straight line L**242**. On the other hand, for each Hall element, object magnet **142** passes closer to Hall elements **40***a* and **40***b* when moving on straight line L**231** than object magnet **142** passes when moving on straight line L**232**. Herein, the intensity of signals output from Hall elements **40***a* and **40***b* increases as the magnetic field strength applied to Hall elements **40***a* and **40***b* from the outside increases. Thus, signal X2 becomes larger than signal X**1**. Signal X2 is a signal output from Hall elements **40***a* and **40***b* when object magnet **142** moves on straight line L**231**, and signal X1 is a signal output from Hall elements **40***a* and **40***b* when object magnet **142** moves on straight line L**232**.

Accordingly, for instance, if the signal output from each Hall element is checked with a threshold, it can be determined whether object magnet **142** is located on straight line L**231** or straight line L**232**, i.e., located apart from magnetic sensor **100** in a right-hand direction or a light-hand direction. In other words, it can be determined whether object magnet **142** is located on the right-hand side or the left-hand side of magnetic sensor **100**. Specifically, when Hall element **40***a* (**40***b*) outputs signal X**1**, magnet **142** is located on straight line L**232**, i.e., at portion S**232** between position PC and position PD in slit **236**. When Hall element **40***a* (**40***b*) outputs signal X**2**, magnet **142** is located on straight line L**231**, i.e., at portion S**231** between position PA and position PB in slit **236**.

FIG. **24** is a block diagram of the magnetic sensor of detection device **230** shown in FIG. **22**. In FIG. **24**, components identical to those of magnetic sensor **100** shown in FIG. **1**A are denoted by the same reference numerals. The magnetic sensor includes detection circuit **10***b*, instead of detection circuit **10**. Detection circuit **10***b* further includes an output terminal (VOUT), interrupt generation unit **80***e*, and interrupt output terminal INT. The output terminal (VOUT) outputs, to the outside as an output signal, a signal which is obtained by performing at least one processing selected from amplification, analog-to-digital conversion, offset correction, and temperature-characteristics correction to the signal input from magneto-resistive element **12**. When the signal input from Hall element **40***a* (**40***b*) is larger than the predetermined threshold, interrupt generation unit **80***e* outputs interrupt signal Si**1** from interrupt output terminal INT. When the signal input from Hall element **40***a* (**40***b*) is equal to or less than the predetermined threshold, interrupt generation unit **80***e* outputs interrupt signal Si**2** from interrupt output terminal INT. Interrupt signal Si**1** indicates that magnet **142** is located apart from magnetic sensor **100** in direction D**11***a*. Interrupt signal Si**2** indicates that magnet **142** is located apart from magnetic sensor **100** in direction D**12***a* opposite to direction D**11***a*.

In magnetic sensor **100***c* shown in FIG. **13**, magneto-resistive element **122** is disposed above magneto-resistive element **121**. Especially, magneto-resistive elements **121** and **122** are arranged such that the center of magneto-resistive element **121** coincides with the center of magneto-resistive element **122**. Such a configuration in which the center of magneto-resistive element **121** coincides substantially with the center of magneto-resistive element **122** is not limited to this.

Another magnetic sensor in which the center of magneto-resistive element **121** coincides substantially with the center of magneto-resistive element **122** will be described below. FIG. **25** is a perspective view of further magnetic sensor **100***f* in accordance with the exemplary embodiment. FIGS. **26** to **32** illustrates a method of manufacturing magnetic sensor **100***f*. In FIGS. **25** to **32**, components identical to those of magnetic sensor **100***d* shown in FIG. **14** are denoted by the same reference numerals.

As shown in FIG. **26**, die pad **130***a* of magnetic sensor **100***f* is connected to die pad **130***b* with connecting part **251**.

Next, as shown in FIG. **27**, substrates **10***c***1** and **10***d***1** are disposed on die pads **130***a* and **130***b*, respectively. Detection circuit **10***c* is provided on substrate **10***c***1**. Detection circuit **10***d* is provided on substrate **10***d***1**.

Next, as shown in FIG. **28**, magneto-resistive element **121** is disposed on detection circuit **10***c*. Magneto-resistive element **122** is disposed on detection circuit **10***d*.

Next, as shown in FIG. **29**, wire **134** electrically connects detection circuit **10***c* to magneto-resistive elements **121**. Wire **134** electrically connects detection circuit **10***c* to lead **132***a*. Wire **134** electrically connects detection circuit **10***d* to magneto-resistive elements **122**. Wire **134** electrically connects detection circuit **10***d* to lead **132***b*.

Next, as shown in FIG. **30**, magneto-resistive elements **121** and **122**, substrates **10***c***1** and **10***d***1**, and wire **134** are molded with sealing resin **138**.

Next, as shown in FIG. **31**, a part of tie bar **291** is cut off, and then leads **132***a* and **132***b* are bent.

Next, as shown in FIG. **32**, the remaining part of tie bar **291** is cut off, and then connecting part **251** is bent to obtain magnetic sensor **100***f* in FIG. **25**.

This structure makes allows the center of magneto-resistive element **121** to be close to the center of magneto-resistive element **122** precisely. Thus, the signals obtained from magneto-resistive element **121** and magneto-resistive element **122** can preferably be substantially the same.

Magnetic sensor **100***f* is formed by the above manufacturing process has the following features.

Lead **132***a* electrically connected to detection circuit **10***c* is extracted from surface **323** of sealing resin **138**. Lead **132***b* electrically connected to detection circuit **10***d*, is extracted from surface **321** opposite to surface **323** of sealing resin **138**. Sealing resin **138** has bottom surface **329** connected to surfaces **321** and **323**. Lead **132***a* connected to detection circuit **10***c* is extracted from a position closer to bottom **329** of sealing resin **138** than lead **132***b* connected to detection circuit **10***d* is, i.e., a lower position. In other words, lead **132***a* connected to detection circuit **10***c* is extracted from near bottom **329** of sealing resin **138**, and lead **132***b* connected to detection circuit **10***d* is extracted from near upper surface **329**A opposite to bottom **329**, i.e., lead **132***a* and lead **132***b* are extracted at heights different from each other, and the difference between the different heights is difference W1 (see FIG. **25**).

Connecting part **251** is extracted from surface **325** which is perpendicular to surfaces **321** and **323** and has an arch shape. The shape of connecting part **251** is not limited to the arch shape. For instance, if a part of connecting part **251** is cut off after being bent, connecting part **251** may have an arch shape having its top portion removed. In other words, connecting part **251** includes a portion extracted from at least two points of surface **325**. Further, boundary L**21** may remain in sealing resin **138** in a portion surrounded by the arch shape of connecting part **251**, i.e., between the two points at which connecting part **251** is extracted from surface **325** (see FIG. **25**). Boundary L**21** is a trace at which sealing resin **138** for sealing magneto-resistive element **121** shown in FIG. **32** is bonded to sealing resin **138** for sealing magneto-resistive element **122**. Herein, the "boundary" may indicate a line remaining in resin, and/or a state where a gap is generated in a part of resin. Further, the "boundary" is located between die pad **130***a* and die pad **130***b*.

Supporting parts **281** that connect between tie bar **291** and each of die pads **130***a* and **130***b* are extracted from surface **327** opposite to surface **325**. Connecting part **251** is extracted from surface **325**.

In magnetic sensor **100***e* shown in FIGS. **26** to **31**, magneto-resistive elements **121** and **122** are disposed on substrates **10***c***1** and **10***d***1**, respectively. Substrates **10***c***1** and **10***d***1** are disposed on die pads **130***a* and **130***b*, respectively. Magneto-resistive elements **121** and **122** may be disposed on die pads **130***a* and **130***b*, respectively while substrate **10***c***1** and **10***d***1** may be disposed on magneto-resistive elements **121** and **122**, respectively. This configuration allows magneto-resistive element **121** to be located close to magneto-resistive element **122**. This configuration provides more approximated magnetic fields to be detected each of which is input to the magneto-resistive element, so that the signals to be output from the magneto-resistive elements are matched accurately.

FIG. **22** shows detection device **230** including magnetic sensor **100** in accordance with the exemplary embodiment, but structure of the detection device is not limited to this.

FIG. **33** is a perspective view of still another detection device **260** in accordance with the exemplary embodiment. FIGS. **34**A and **34**B are partial top views of detection device **260**. In FIGS. **34**A and **34**B, unnecessary structure for description is omitted, as necessary, to be described. Detection device **260** includes case **261**, guide **262**, linkage mechanism **263**, shaft **264**, and magnetic sensor **100**. Shaft **264** may also be described as a shift lever.

Slit **266** is provided in case **261**.

Slit **266** has portions S**261**, S**262**, and S**266**. Portions S**261** and S**262** extend slenderly along straight lines L**261** and L**262** parallel with each other, respectively. Portion S**266** connects portion S**261** to portion **262**. In FIG. **33**, slit **266** has an H-shape. Guide **262** is provided in an inner wall of slit **266**. In accordance with the exemplary embodiment, guide **262** is a recess provided in the inner wall of slit **266**.

Shaft **264** is connected to linkage mechanism **263**. When a user operates shaft **264**, a part of a member constituting linkage mechanism **263** moves along guide **262**.

Linkage mechanism **263** includes supporting part **263***a* connected to shaft **264**, movable body **263***b* connected to supporting part **263***a*, belt **263***c* connected to movable body **263***b*, movable body **263** connected to belt **263***c*, and object magnet **142** connected to movable body **263**.

Supporting part **263***a* is slidable in slit **266** along guide **262**. In other words, supporting part **263***a* can move along straight line L**262** and straight line L**261**. Further, straight line L**262** and straight line L**261** can be described as traces along which supporting part **263***a* moves.

Movable body **263***b* is configured to convert an up-down movement of supporting part **263***a* into a rotational movement. Further, by moving movable body **263***b* horizontally, the rotation amount thereof is changed. To achieve this mechanism, movable body **263***b* has a cross section having a trapezoid shape. That is, a portion of movable body **263***b* closer to supporting part **263***a* has a diameter larger than that of a portion farther from supporting part **263***a*.

Belt **263***c* connects movable body **263***b* to movable body **263***d*, and transmits the rotational movement of movable body **263***b* to movable body **263***d*.

FIG. **34**C is a front view of object magnet **142**. Movable body **263***d* has a cylindrical shape such that movable body **263***d* rotates due to a driving force transmitted through belt **263***c*. Object magnet **142** is connected to movable body **293***d*, thereby giving a change of magnetic field of object magnet **142** to magnetic sensor **100**. In this way, linkage mechanism **263** is coupled with shaft **264** (shift lever), and configured such that a rotation amount of movable body **263***d* is changed according to horizontal movement of shaft **264**. Thus, a difference in rotation angle of object magnet **142** is generated between position PB and position PB. As a result, positions PA, PB, PC, and PD can be determined by only one magnetic sensor **100**.

Linkage mechanism **263** having this structure may be expressed as a variable speed pulley.

When linkage mechanism **263** having this structure is employed, Hall elements **40***a* and **40***b* of magnetic sensor **100** and a circuit used for detecting the output from Hall elements **40***a* and **40***b* are not essential.

In the exemplary embodiment, terms, such as "upper surface", and "when viewed from above" indicate relative directions determined only by relative physical relationship between component members of the magnetic sensor, but do not indicate absolute directions, such as a vertical direction.

REFERENCE MARKS IN THE DRAWINGS

10 detection circuit
12 magneto-resistive element
12*a*-**12***h* magneto-resistive element
12*t*, **12***s* magnetic resistance pattern
12*ac*, **12***bd*, **12***eg*, **12***fh* node (midpoint)
12*x* magneto-resistive element group
12*y* magneto-resistive element group
14*a*-**14***d* amplifier
15 offset control circuit
16*a*, **16***b* differential amplifier
17 gain control circuit
18*a*, **18***b* AD converter
40*a*, **40***b* Hall element
42*a*, **42***b* amplifier
44*a*, **44***b* comparator
60*a*-**60***c* regulator
70 processing unit
70*a* angle detection circuit
70*b* rotation number detection circuit
70*c* offset-temperature-characteristic correction circuit
70*d* gain-temperature-characteristic correction circuit
70*e* automatic correction circuit
80*a*, **80***b* oscillator
80*c* memory
80*d* temperature sensor
90, **91** diagnostic circuit
100 magnetic sensor

100*a*1-**100*a*4** wiring
100*b*1-**100*b*4** wiring
112*a*, **112*b*** resistor
112*a*1, **112*a*2**, **112*b*1**, **112*b*2** current path
WB**1**, WB**2** bridge circuit
121, **122** magneto-resistive element
121*a*, **122*a*** magneto-resistive element group
121*b*, **122*b*** magneto-resistive element group
130, **130*a***, **130*b*** die pad
132, **132*a***, **132*b*** lead
134, **134*b*** wire
138 sealing resin
142 object magnet
144 rotation shaft
146 bearing
150 rotation detection device
201*a* substrate
201*b* substrate
201*c* substrate
201*d* substrate
203 electrode
230 detection device

The invention claimed is:

1. A magnetic sensor configured to be used with a magnet, the magnetic sensor comprising:
- a magneto-resistive element;
- a Hall element disposed in a predetermined direction from the magneto-resistive element; and
- a detection circuit that receives a signal from the magneto-resistive element and a signal from the Hall element input thereto,
- wherein the detection circuit includes:
  - a processing unit configured to output a signal to an outside as an output signal, the signal being obtained by performing, to the signal input from the magneto-resistive element, at least one processing selected from amplification, analog-to-digital conversion, offset correction, and temperature-characteristics correction; and
  - an interrupt generation unit configured to output signals in response to the signal input from the Hall element,
- wherein the signal output from the processing unit indicates a position of the magnet when viewed in the predetermined direction, and
- wherein the interrupt generation unit is configured to:
  - output a first interrupt signal when the signal input from the Hall element is larger than a predetermined threshold, the first interrupt signal indicating that the magnet is positioned in a first direction from the magnetic sensor, the first direction being perpendicular to the predetermined direction; and
  - output a second interrupt signal when the signal input from the Hall element is less than or equal to the predetermined threshold, the second interrupt signal indicating that the magnet is positioned in a second direction from the magnetic sensor, the second direction being opposite to the first direction.

2. A detection device comprising:
the magnetic sensor of claim **1**; and
magnet.

3. The detection device of claim **2**,
- wherein the first interrupt signal indicates that the magnet is located apart from the magnetic sensor in the first direction, and
- wherein the second interrupt signal indicates that the magnet is located apart from the magnetic sensor in a second direction opposite to the first direction.

4. A detection device comprising:
- a magnetic sensor including a magneto-resistive element and a Hall element; and
- a magnet movable along a first straight line and a second straight line parallel with each other,
- wherein the magneto-resistive element overlaps a third straight line when viewed from above, the third straight line being parallel with the first straight line and located at equal distances from the first straight line and the second straight line,
- wherein the Hall element is provided between the first straight line and the third straight line, and
- wherein the magneto-resistive element and the Hall element are arranged in a direction perpendicular to the third straight line.

5. The detection device of claim **4**, wherein the third straight line passes substantially through a center of the magneto-resistive element.

6. The detection device of claim **4**, wherein the magnetic sensor outputs an interrupt signal when the magnet is located on the first straight line.

7. The magnetic sensor of claim **1**,
- wherein the first interrupt signal indicates that the magnet is located apart from the magnetic sensor in the first direction, and
- wherein the second interrupt signal indicates that the magnet is located apart from the magnetic sensor in the second direction.

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